Assessment of Greenland Turbot in the Eastern Bering Sea and Aleutian Islands

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Summary

Relative to last year's assessment, the following changes have been made in the current assessment.

New input data

1. 2003 and 2004 catch data
2. 2003 (and limited 2004) fishery catch-at-length by gear type
3. EBS shelf survey 2004 biomass and length composition estimates
4. EBS slope survey 2004 biomass and length composition estimates
5. An updated aggregated longline survey data index for the EBS and Aleutian Islands regions

Assessment model

There were no major changes to the assessment model.

Assessment results

The shelf survey provided some indication of a recruitment event due to the presence of small Greenland turbot. The 2004 shelf-survey biomass estimate was down by about 2% from the 2003 estimate. The slope survey biomass was 38% higher than the 2002 level. However, the longline survey trend continues downward at about 9% per year. The value of $B_{40\%}$ was based on the mean estimated recruitment for the period 1978-2003. Results indicate that the long-term average female spawning biomass is around 51,600 tons. The current estimate of the year 2005 female spawning biomass is about 55,600 t. Given the current model structure and general uncertainty about stock structure, an ABC based on the recent 5-year average fishing mortality **3,930 t is recommended.** This is justified based on projections showing further declines in abundance and a recent analysis that suggests that the natural mortality rate should be revised downward. The overfishing level, based on the adjusted $F_{35\%}$ rate is **19,200 t** corresponding to a full-selection F of 0.50.

Introduction

Greenland turbot (*Reinhardtius hippoglossoides*) within the US 200-mile exclusive economic zone are mainly distributed in the eastern Bering Sea (EBS) and Aleutian Islands region. Juveniles are believed to spend the first 3 or 4 years of their lives on the continental shelf and then move to the continental slope (Alton et al. 1988). Juveniles are absent in the Aleutian Islands regions, suggesting that the population in the Aleutians originates from the EBS or elsewhere. In this assessment we assume that the Greenland turbot found in the two regions represent a single management stock. NMFS initiated a tagging study in 1997 to supplement earlier international programs. Results from tag returns suggest that this species is capable of movement over large areas.

Prior to 1985 Greenland turbot and arrowtooth flounder were managed together. Since then, the Council has recognized the need for separate management quotas given large differences in the market value between these species. Furthermore, the abundance trends for these two species are clearly distinct (e.g., Wilderbuer and Sample 1992).

The American Fisheries Society uses “Greenland halibut” as the common name for *Reinhardtius hippoglossoides* instead of Greenland turbot. To avoid confusion with the Pacific halibut, *Hippoglossus stenolepis*, we retain the common name of Greenland turbot which is also the “official” market name in the US and Canada (AFS 1991). For further background on this assessment and the methods used refer to Ianelli and Wilderbuer (1995).

Catch history and fishery data

Catches of Greenland turbot and arrowtooth flounder were not reported separately during the 1960s. During that period, combined catches of the two species ranged from 10,000 to 58,000 t annually and averaged 33,700 t. Beginning in the 1970s the fishery for Greenland turbot intensified with catches of this species reaching a peak from 1972 to 1976 of between 63,000 t and 78,000 t annually (Fig. 5.1). Catches declined after implementation of the MFCMA in 1977, but were still relatively high in 1980-83 with an annual range of 48,000 to 57,000 t (Table 5.1). Since 1983, however, trawl harvests declined steadily to a low of 7,100 t in 1988 before increasing slightly to 8,822 t in 1989 and 9,619 t in 1990. This overall decline is due mainly to catch restrictions placed on the fishery because of declining recruitment. For the period 1992–1997, the Council set the TAC’s to 7,000 t as an added conservation measure due to concerns about apparent low levels of recruitment in the past several years. This has resulted in primarily bycatch-only fisheries. The distribution of the Greenland turbot catches has been fairly consistent in recent years (Figs. 5.2 and 5.3).

Catch information prior to 1990 included only the tonnage of Greenland turbot retained Bering Sea fishing vessels or processed onshore (as reported by PacFIN). Discard levels of Greenland turbot have typically been highest in the sablefish fisheries (at about one half of all sources of Greenland turbot discards during 1992-2002) while Pacific cod fisheries and the Greenland turbot directed fishery also have contributed substantially to the discard levels (Table 5.2). Greenland turbot were 73% retained in the 2003 Bering Sea fisheries.

Catch

The catch data were used as presented above for both the longline and trawl fisheries. The early catches included Greenland turbot and arrowtooth flounder together. To separate them, we assumed that the ratio of the two species for the years 1960-64 was the same as the mean ratio caught by USSR vessels from 1965-69.

Size and age composition

No age composition information is available from the fisheries or surveys. However, limited survey size-at-age data (useful for estimating growth and growth variability) were available from 1975, 1979-1982. Extensive length frequency compositions have been collected by the NMFS observer program from the period 1980 to 1991. The length composition data from the trawl and longline fishery and the expected values from the assessment model are presented in previous assessments. This information is used in the assessment model and adds to our ability to estimate size-specific selectivity patterns in addition to year-class variability.

Resource Surveys

In 2004 NMFS scientists surveyed the Aleutian Islands region with bottom trawls and longline gear and both the slope and shelf regions of the EBS were surveyed with trawl gear. The 2004 Aleutian Islands bottom trawl survey estimate was 11,300 t, an increase of 15% from the 2002 survey estimate (Table 5.3). However, the 11,300 t is below the 1990-2004 average level of 16,500 t. The distribution of Greenland turbot from the recent Aleutian Islands surveys are shown in Fig. 5.4. In 2004 a relatively large fraction of the Greenland turbot (29%) were found in the eastern-most area of the Aleutian Islands survey (Table 5.3). For modeling purposes, the Aleutian Islands component of the Greenland turbot stock is omitted.

Abundance estimates for juvenile Greenland turbot on the EBS shelf are provided annually by AFSC trawl surveys. The older juveniles and adults on the slope were surveyed every third year from 1979-1991 (also in 1981) as part of a U.S.-Japan cooperative agreement. The slope surveys were conducted by Japanese shore-based (Hokuten) trawlers chartered by the Japan Fisheries Agency until 1985. In 1988, the NOAA R/V Miller Freeman was used to survey the resources on the EBS slope region. In this same year, chartered Japanese vessels performed side-by-side experiments with the R/V Miller Freeman for calibration purposes. Due to limited vessel time, the R/V Miller Freeman sampled a smaller area and fewer stations than the previous years. The Miller Freeman sampled 133 stations over a depth interval of 200-800 m while during earlier slope surveys the Japanese vessels usually sampled 200-300 stations over a depth interval of 200-1,000 m . In 2002 the AFSC reestablished the bottom trawl survey of the upper continental slope of the eastern Bering Sea. This survey is planned to be done every two years and has improved sampling effort Greenland turbot habitat areas.

The trawl slope-surveys are likely to represent under-estimates the actual biomass of Greenland turbot for a number of reasons, hence, these are treated as relative indices of abundance. For example, the species appears to extend beyond the area of the survey and that the ability to tend bottom in the deeper waters may be compromised. A similar issue likely affects the distribution of Greenland turbot on the shelf region, particularly given the extent of the cold pool and warm conditions in recent years (Paul Spencer, pers. comm., Fig. 5.5).

The combined estimates from the shelf and slope indicate a decline in EBS abundance for the 4 years of observations that were available during 1979-1985. After 1985, the slope biomass estimates (comparable since similar depths were sampled) have averaged 55,000 t—the 2004 level is 59,000 t. The average shelf-survey biomass estimate during the last 11 years (1993-2004) is 28,000 t.

The following table summarizes the sampling that has occurred for the EBS bottom trawl survey data since 1982:

Year	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	
No. hauls	329	354	355	353	354	342	353	353	352	351	336	
No. Lengths	969	951	536	196	195	82	200	183	232	360	440	
Year	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
No. hauls	355	355	356	355	356	355	353	352	355	355	356	376
No. Lengths	400	398	313	297	197	93	207	248	274	322	622	na

Currently, the domestic longline survey effort extends into the Bering Sea and part of the Aleutian Islands (in alternate years). This new sampling area represents a smaller region than in past but shows that about 25% of the population along the slope regions is found within the northeast (NE) and southeast (SE) portions of the Aleutian Islands compared to the abundances along the slope of the EBS:

Relative Population No. (RPN)				Year					
Area	1996	1997	1998	1999	2000	2001	2002	2003	2004
Bering 4		11,729		13,072		16,082		11,965	
Bering 3		6,172		6,156		5,005		3,784	
Bering 2		27,936		33,848		24,766		24,660	
Bering 1		13,491		10,068		4,788		6,206	
NE Aleutians	23,133		16,124		12,987		10,942		8,551
SE Aleutians	2,142		1,806		1,201		1,397		937
Bering Sea		59,328		63,144		50,641		46,616	
Aleutians	25,275		17,930		14,188		12,339		9,487
Combined	112,907	76,440	80,094	81,356	63,381	65,247	55,119	60,061	42,380

The combined time series shown above (1996-2004) was used as a relative abundance index (Fig. 5.6). It was computed by taking the average RPN from 1996-2004 for both areas and computing the average proportion. The combined *RPN* in each year (RPN_t^c) was thus computed as:

$$RPN_t^c = I_t^{AI} \frac{RPN_t^{AI}}{p^{AI}} + I_t^{EBS} \frac{RPN_t^{EBS}}{p^{EBS}}$$

where I_t^{AI} and I_t^{EBS} are indicator function (0 or 1) depending on whether a survey occurred in either the Aleutian Islands or EBS, respectively. The average proportions (1996-2004) are given here by each area as: p^{AI} and p^{EBS} . Note that each year data are added to this time series, the estimate of the combined index changes (slightly) in all years and that this approach assumes that the population proportion in these regions is constant. A coefficient of variation of 20% for this index was assumed.

A time series of estimated size composition of the population was available for the shelf and slope trawl surveys and for the longline survey. The slope surveys typically sample more turbot than the shelf trawl surveys; consequently, the number of fish measured in the slope surveys is greater. The Greenland turbot size compositions from the 2004 Aleutian Islands and EBS slope trawl surveys are given in Fig. 5.7. The EBS shelf trawl survey extended into the northern region in 2004 and found relatively large numbers of smaller Greenland turbot (Fig. 5.8). This provides additional evidence that the stock extends further north than the standard survey area and could be indicative of a successful recruitment event. The length frequency from the longline survey is shown in Fig. 5.9.

Scientific research catches are reported to fulfill requirements of the Magnuson-Stevens Fisheries Conservation and Management Act. The following table documents annual research catches (1977 - 1998) from NMFS longline and trawl surveys (in tons):

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
NMFS Bottom trawl surveys	62.48	48.36	103.01	123.6	15.14	0.73	175.22	72.84	0.56	18.48
Cooperative Longline surveys	3	3	6	11	9	7	8	7	11	6
Year	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
NMFS Bottom trawl surveys	0.64	0.85	11.37	0.88	1.43	8.51	1.44	1.47	4.64	1.38
Domestic Longline surveys										
Cooperative Longline surveys	16	10	10	22	23	23				

Model Structure

The use of the stock synthesis program (Methot 1990) to model the eastern Bering Sea component of Greenland turbot stock was presented in previous assessments (Ianelli et al. 1994, 1995). Before 1994, stock assessments of Greenland turbot in the eastern Bering Sea and Aleutian Islands have relied in part on stock reduction analysis (SRA) to provide historical trends in the fishery (Wilderbuer and Sample 1992). As with past years, the length-version of the stock synthesis program (Methot 1990) was used for this assessment (updated to the 2003 version of the computer program). Catch data used in the stock synthesis model were from 1960 to 2004. It was assumed that the stock was at or close to its virgin biomass level at the beginning of the catch data time series.

Model parameters were estimated by maximizing the log likelihood (L) of the predicted observations given the data. Data are classified into different components. For example, age composition from a survey and catch per unit effort (CPUE) from a fishery are different components. The total L is a sum of the likelihoods for each component. The total L may also include a component for a stock-recruitment relationship and penalty functions to help stabilize parameter estimates. The likelihood components may be weighted by an emphasis factor. For Greenland Turbot in the EBS the model included two fisheries, those using longline and trawl gear, and three surveys. Table 5.4 summarizes the extent of the data used in the different likelihood components. All emphasis factors were set to 1.0, effectively relying on proper weights from the assumed (or in most cases, estimated) variances for the data sources.

Annual recruitments are estimated as parameters in the model, they can be thought of as “anomalies” from an underlying stock-recruitment curve. These recruitment anomalies can be due to process and observation errors. Process errors refer to the real differences from the mean stock-recruitment curve caused by natural variation in recruitment success. Observation errors refer to our ability to estimate the true recruitment levels due to sampling problems. In this application, observation error is considered negligible compared to the magnitude of recruitment variability (process error). Consequently, the underlying parameters of the stock-recruit curve play an insignificant role in fitting the model to the data. For further details on the model specifications of the length-version of the stock synthesis program, see Thompson *et al.* (Pacific cod chapter, this volume).

Selectivity Patterns

A dome-shaped size-based selectivity function (Methot 1990) was estimated for each survey and fishery described below. For the trawl fishery, the periods of length frequency data collections from the domestic and foreign fleet did not overlap. Consequently, we treated the foreign and domestic trawl data as from a single fishery and simply let the selectivity pattern be different between the respective periods. Because larger fish have been observed in the recent EBS shelf region trawl surveys, selectivity was also was estimated separately for two periods: 1994-present and 1982-1993.

Parameters estimated independently

Natural mortality, length at age, length-weight relationship

The natural mortality of Greenland turbot was assumed to be 0.18. This estimate was used because it is slightly less than that of other flatfish species with a slightly lower maximum age. Greenland turbot taken by the commercial fishery have been aged as old as 21 years. A recent study (Cooper et al., In review) found that based on relating GSI and life-history characteristics, natural mortality should be lower, close to 0.10. For this assessment, an alternative ABC value is provided with this value of natural mortality (using Tier 5 calculations). A full evaluation using alternative natural mortality rates (pending review) will be forthcoming in future assessments.

Parameters describing length-at-age are estimated within the model. We do assume that the length at age 1 is the same for both sexes and that the variability in length at age 1 has an 8% CV and that the variability in length at age 21 has a CV of 7%. This appears to encompass the observed variability in length-at-age.

As in the previous assessments, size-at-age information from surveys conducted between 1976-82 were used in the model to help estimate the relationship between age and length. The length-weight relationship for Greenland turbot estimated by Ianelli et al. (1993) was:

$$w = 2.69 \times 10^{-6} L^{3.3092} \quad \text{for females}$$

and

$$w = 6.52 \times 10^{-6} L^{3.068} \quad \text{for males}$$

where L = length in mm, and w = weight in grams.

Maturation and fecundity

Maturation and fecundity by size or age is poorly understood for Greenland turbot. Alton *et al.* (1988) present the results from studies of Greenland turbot in different areas in addition to the EBS region. For this analysis, we chose a logistic size-maturity relationship which has 50% of the female population mature at 60 cm; 2% and 98% of the females are assumed to be mature at about 50 and 70 cm respectively. This is based on an approximation from D'yakov's (1982) study.

Parameters estimated conditionally

The key parameters estimated within the model include:

- Annual recruitment estimates from 1960-2004 (1965-1969 aggregated to have a single mean value),
- Selectivity parameters for the 2 fisheries, and 3 surveys,
- Growth parameters: 5 parameters (2 for each sex, one in common),
- Parameter that scales the expected value of recruitment, and
- Effective effort-fishing mortality rates for trawl and longline fisheries (solved by matching predicted catch biomass to the observed catch biomass exactly), 1960-2004.

Model evaluation

Size composition data are not available until 1977 hence we are unable to resolve recruitment strength information during the early period (1960s) with the model. Based on earlier assessments (e.g., Ianelli et al. 1999), setting the individual recruitment estimates from 1960-69 equal to that predicted by an equilibrium stock-recruitment relationship gave a poor fit to the size composition data and a high unfished biomass (>1.8 million mt). When all recruitment deviations were estimated (the full model), a single large deviation resulted in the early part of the time series. This indicated a year class more than an order of magnitude greater than the mean estimated recruitment since 1970. Both the full model and the equilibrium recruitment models were therefore unsatisfactory. To compensate, we pooled recruitment deviation estimates from 1965-69 as in Ianelli et al. (1993). The assumed slope-survey catchability was fixed as before at 0.75. A complete analysis of alternative model configurations was not attempted this year due to complexity related to selectivities, gear types, and general paucity of information specific to Greenland turbot.

Trends in Abundance

The fits to the abundance indices are given in Fig. 5.10. The assessment model predictions for shelf survey biomass are considerably below the observed estimates during the early years. Since 1993, the point where selectivity is allowed to change, the fit to the index is biased high. The shift in selectivity was intended to reflect the appearance of larger Greenland turbot on the shelf than in the past. Some modeling that better accounts for habitat changes (e.g., extent of the cold pool or some other environmental factor) may be preferred to more reasonably reflect changes in distribution. This is an area for future research. The reason that the model fits the early period of the shelf trawl survey index poorly is because such high levels of recruitment are inconsistent with observations of numbers of older fish later in the time series. The overall trend for the slope survey estimates is mimicked by the assessment model. The general trend of the longline survey index shows decreasing numbers that are tracked by the model.

The biomass of Greenland turbot increased during the 1970s from the early 1960s level and is currently about 43% of the unfished level. The 2004 total beginning of the year biomass (age 1 and older) estimate is about 98,300 (Table 5.5; Fig. 5.11). In past years, harvest levels of Greenland turbot were set using extra precaution due to the lack of recruitment. For example, the model excludes biomass estimates from the Aleutian Islands, which averages about one fourth to one third of the adult population biomass.

The historical fishing mortality rates (combined gears) increased over time and was highest in 1980 through 1983 (Table 5.5). A comparison of this year's model result with a similar model from the 2003 assessment is also presented in Table 5.5. The estimated historical numbers at age is given in Table 5.6.

Selectivity

Selectivity of Greenland turbot varied considerably between all of the surveys and fisheries. The shelf survey selected only small fish whereas the slope survey caught much larger fish. A similar pattern was observed between the trawl and longline fisheries with the longline fishery consistently catching larger Greenland turbot (Fig. 5.12). Note that the average selectivity estimates for the slope and shelf surveys indicate that our surveys do not sample intermediate size fish (35-50cm) very well. The reason for this is not clear; however, we feel that it is related to the apparent bi-modality in the size distribution observed in the trawl fishery. The age-equivalent sex-specific selectivity estimates (for 2004) from each gear type for Greenland turbot in the BSAI is given in Table 5.7. These are approximate due to the fact that selectivity processes are modeled as a function of size. Similar, approximate age-and-sex-specific weights (and maturity) are specific to each fishery (Table 5.8).

Fit to Size Composition Data

Size composition observations from the fisheries and surveys are generally poorly matched by the model predictions (Appendix 5.1). In some years, relatively few fish were measured so adjustments of the model to those data would depend on the trade-off in fitting other data, which may have had more extensive sampling. Second, unaccounted fish movement and hence changing availability affects fits to size composition data when an "average" gear selectivity is used. Finally, natural mortality rate is undoubtedly variable among cohorts and years, the extent of which would affect our ability to model the age structure of the population accurately. The nature of the inconsistencies among data types is presented below, particularly as they pertain to assessing the current stock status.

Recruitment

Recruitment of young juvenile Greenland turbot has been poor since the early 1980s based on EBS shelf trawl surveys. There were several strong year-classes through the 1970s, which were followed by moderate recruitment of Greenland turbot during the 1980s and poor levels through the 1990s (Fig. 5.13). There are some signs of improvement since 2000 but these estimates must be viewed with caution. Preliminary analyses on fitting the stock-recruitment relationship indicated that the residuals were highly auto-correlated. Therefore, the assumptions required to pursue stock-recruitment analyses are unjustified.

Projections and harvest alternatives

Maximum Sustainable Yield

Maximum sustainable yield (MSY) calculations require assumptions about the stock recruitment relationship, which for Greenland turbot may be impractical as many functional forms can fit the data equally well. As presented above, the harvest strategy relative to reductions in spawning biomass per recruit (e.g., $F_{40\%}$) was selected in the absence of information on the stock-recruitment productivity relationship required for calculating MSY levels.

ABC and Overfishing levels

The recommended harvest levels vary considerably among models depending on the assumptions made about the catchability coefficients from the slope-trawl survey (Ianelli et al. 1999). Since there are several areas of uncertainty surrounding this assessment, for the basis for recommendations we selected a conservative configuration (assuming slope-survey catchability=0.75). The status of the projected spawning biomass in year 2005 relative to $B_{40\%}$ would place Greenland turbot in Tier 3a of Amendment 56.

We computed $B_{40\%}$ value by using the mean recruitment estimated for the period 1978-2003. The results indicate that the long-term average female spawning biomass is around 51,600 tons. The current estimate of the year 2005 female spawning biomass is about 55,600 t.

Past recommendations have intentionally been extra conservative with the idea of promoting the recovery of Greenland turbot in the EBS and Aleutian Islands region, the stock appears to be on a continuing decline. While the stock is technically not overfished and is currently above $B_{40\%}$, we feel that extra caution is warranted. The new survey information from the slope region provides insight on the abundance of Greenland turbot in their main habitat area (the most recent survey prior to that of 2002 was in 1991). However, we feel that an ABC based on the recent 5-year average fishing mortality is recommended which is **3,930 t.** We feel that this is justified since in the projections we anticipate further declines given the current estimate of the age composition of the stock.

Our recommendation for overfishing, based on the adjusted $F_{35\%}$ rate is **19,200 t** corresponding to a full-selection F of 0.50. The value of the Council's overfishing definition depends on the age-specific selectivity of the fishing gear, the somatic growth rate, natural mortality, and the size (or age) -specific maturation rate. As this rate depends on assumed selectivity, future yields are sensitive to relative gear-specific harvest levels. Because harvest of this resource is not allocated by gear type, the unpredictable nature of future harvests between gears is an added source of uncertainty. However, this uncertainty is considerably less than uncertainty related to treatment of survey biomass levels, i.e., factors which contribute to estimating absolute biomass (Ianelli et al. 1999).

For contrast, a Tier 5 calculation using the lower natural mortality rate (Cooper et al. In review) gives an ABC value of 4,420 t. The same calculation using the default value for natural mortality (0.18) gives an ABC of 7,960 t. These values were calculated as the sum of 2004 EBS shelf and slope trawl survey biomass estimates (59,000 t) times 0.75*M*.

Standard harvest scenarios and projections

This year, a standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2004 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2005 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2004 (here assumed to be 2,156 t). In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2006, are as follow ("*max* F_{ABC} " refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, *F* is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, *F* is set equal to the author's recommend level. Here values equal to Scenario 4 (5-year average *F*) were selected.

Scenario 3: In all future years, *F* is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, *F* is set equal to the 2000-2004 average *F*. (Rationale: For some stocks, TAC can be well below ABC, and recent average *F* may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, *F* is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Scenarios 1 through 5 were projected 13 years from 2004 (Table 5.9).

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above ½ of its MSY level in 2005 and above its MSY level in 2015 under this scenario, then the stock is not overfished.)

Scenario 7: In 2005 and 2006, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2017 under this scenario, then the stock is not approaching an overfished condition.)

Our projection model run under these conditions indicates that for Scenario 6, the Greenland turbot stock is not overfished based on the first criterion (year 2005 spawning biomass estimated at 55,600 t relative to ½ $B_{35\%}$ = 22,600 tons). Under the guidelines, since the year 2005 biomass estimate is well above the $B_{35\%}$ level (and $B_{40\%}$) we have determined that the stock is not overfished.

Projections of fishable biomass 13 years into the future under alternative fishing mortality rates were examined. The same natural mortality and growth parameters that were used in the previous stock synthesis runs were employed for the projections. The results fishing at the maximum permissible and at the 5-year average F both suggest a continued decline in spawning biomass until about 2009 (Fig. 5.14). However, fishing at the 5-year average F is more likely to keep the stock size above the $B_{35\%}$ level (the expectation is that it will drop to 49,300 compared to the $B_{35\%}$ level of 45,100). Projections with fishing at the maximum permissible level result in an expected value of spawning biomass of 35,200 t in 2008.

Under Scenarios 6 and 7, the projected spawning biomass for Greenland turbot is not currently overfished, nor is it approaching an overfished status.

Other Considerations

Subarea Allocation

In this assessment, we have adopted the hypothesis proposed by Alton et al. (1989) regarding the stock structure of Greenland turbot in the eastern Bering Sea and Aleutian Islands regions. Briefly, spawning is thought to occur throughout the adult range with post-larval settlement occurring on the shelf in shallow areas. The young fish on the shelf begin to migrate to the slope region at about age 4 or 5. In our treatment, the spawning stock includes adults in the Aleutian Islands and the eastern Bering Sea. In support of this hypothesis, we examined the length compositions from the Aleutian Islands surveys and found a lack of small Greenland turbot, which suggests that these fish migrate from other areas (Ianelli et al. 1993). Historically, the catches between the Aleutian Islands and eastern Bering Sea has varied (Table 5.10).

Since we acknowledge having limited information on the movement and recruitment processes for this species and in the interest of harvesting the "stock" evenly, we recommend that the ABC be split between regions. Based on eastern Bering Sea slope survey estimates and Aleutian Islands surveys, the proportion of the adult biomass in the Aleutian Islands region has ranged from 24% to 49%. We therefore recommend the ABC for the Aleutian Islands be set 31% of the total ABC, with 69% allocated to the eastern Bering Sea. These rates are based on mean values observed from biomass estimates and give the following region-specific allocation:

Aleutian Islands	1,210
Eastern Bering Sea	2,720
Total	3,930

Ecosystem considerations

Greenland turbot have undergone dramatic declines in the abundance of immature fish on the EBS shelf region compared to observations during the late 1970's. It may be that the high level of abundance during this period was unusual and the current level is typical for Greenland turbot life history pattern. Without further information on where different life-stages are currently residing, we can only speculate on the plausibility of this scenario. Several major predators on the shelf were at relatively low stock sizes during the late 1970's (e.g., Pacific cod, Pacific halibut) and these increased to peak levels during the mid 1980's. Perhaps this shift in abundance has reduced the survival of juvenile Greenland turbot in the EBS shelf. Alternatively, the shift in recruitment patterns for Greenland turbot may be due to the documented environmental regime that occurred during the late 1970's. That is, perhaps the critical life history stages are subject to different oceanographic conditions that affect the abundance of juvenile Greenland turbot on the EBS shelf.

Currently, the ecosystem group within the REFM Division is actively evaluating the pattern of mortality between different species in the EBS. One aspect of this work involves developing a multi-species model. Results from this work indicate that Greenland turbot has been an important predator.

A tagging study of Greenland turbot conducted by the NMFS Auke Bay Lab staff is continuing. This year scientists aboard the longline survey tagged and released 100 Greenland turbot bringing the total number of releases up to 841. In 2002 a Greenland turbot at large for over 16 years and recaptured on the Bering Sea slope area was reported. This individual fish was tagged in the Sea of Okhotsk, suggesting that Greenland turbot in the EBS/AI may not be a closed population. In addition, the Auke Bay lab scientists tagged 45 Greenland turbot with electronic (archival) tags in the Bering Sea in 2003. Of these, 4 males were recaptured and the temperature and depth data translated. Preliminary examinations of these data show interesting seasonal patterns with high levels of activity occurring in mid-January, perhaps related to spawning behavior.

Summary

The pattern of total fishing mortality relative to spawning biomass suggests that the EBS Greenland turbot stock is approaching the $B_{40\%}$ level, but that historically the fishing mortality was below the $F_{40\%}$ level (Fig. 5.15). The management parameters of interest derived from this assessment are presented in Table 5.11.

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Tables

Table 5.1. Catches of Greenland turbot by gear type (including discards) since implementation of the MFCMA.

Year	Trawl	Longline& Pot	Total
1977	29,722	439	30,161
1978	39,560	2,629	42,189
1979	38,401	3,008	41,409
1980	48,689	3,863	52,552
1981	53,298	4,023	57,321
1982	52,090	32	52,122
1983	47,529	29	47,558
1984	23,107	13	23,120
1985	14,690	41	14,731
1986	9,864	0	9,864
1987	9,551	34	9,585
1988	6,827	281	7,108
1989	8,293	529	8,822
1990	10,869	577	11,446
1991	6,245	1,617	7,863
1992	749	3,003	3,752
1993	1,145	7,323	8,467
1994	6,426	3,845	10,272
1995	3,978	4,215	8,194
1996	1,653	4,902	6,555
1997	1,209	5,989	7,199
1998	1,830	7,319	9,149
1999	1,799	4,057	5,857
2000	1,946	5,027	6,973
2001	2,149	3,163	5,312
2002	1,033	2,605	3,638
2003	931	2,495	3,426
2004*	662	1,494	2,156

* Estimate as of 10/30/2004, source: NMFS Regional Office, Juneau, AK

Table 5.2. Estimates of discarded and retained (mt) Greenland turbot based on NMFS Blend estimates by directed fishery, 1992-2003.

	Greenland turbot		**Sablefish**		**Pacific cod**		**Rockfish**		**Flatfish**		**Others**		**Combined**	
Year	Retained	Discarded	Retained	Discarded	Retained	Discarded	Retained	Discarded	Retained	Discarded	Retained	Discarded	Retained	Discarded
1992	62	13	196	2,121	135	557	180	103	13	3	107	261	694	3,058
1993	5,685	332	235	880	160	108	572	87	19	185	10	194	6,681	1,786
1994	6,316	368	194	2,305	149	211	316	37	27	235	38	76	7,040	3,232
1995	5,093	327	157	1,546	145	284	362	25	5	102	28	121	5,789	2,405
1996	3,451	173	200	1,026	170	307	598	113	171	63	143	140	4,733	1,822
1997	4,709	521	129	619	270	283	202	19	212	92	18	125	5,539	1,659
1998	6,905	301	125	171	278	154	42	2	628	249	123	171	8,101	1,048
1999	4,009	227	179	120	180	50	25	2	600	269	134	61	5,128	729
2000	4,798	177	192	253	130	108	39	1	838	176	186	75	6,183	790
2001	2,727	89	171	325	203	92	431	30	764	337	95	47	4,391	921
2002	1,979	73	144	207	210	139	175	18	301	217	124	49	2,934	703
2003	1,792	45	114	529	154	93	198	5	197	71	315	311	2,546	962

Table 5.3. Survey estimates of Greenland turbot biomass (t) for the Eastern Bering Sea shelf and slope areas and for the Aleutian Islands region, 1975-2004. Note that the shelf survey estimates for 2001-2004 were updated this year.

	Eastern Bering Sea			Aleutian Islands region only	Entire Aleutian survey	Percent in eastern area
Year	**Shelf**	**Slope**	**Shelf and Slope Combined**			
1975	126,700					
1979	225,600	123,000	348,600			
1980	172,200				48,700*	
1981	86,800	99,600	186,400			
1982	48,600	90,600	139,200			
1983	35,100				63,800*	
1984	17,900					
1985	7,700	79,200	86,900			
1986	5,600				76,500*	
1987	10,600					
1988	14,800	42,700	57,500			
1989	8,900					
1990	14,300					
1991	13,000	40,500	53,900	10,122	11,925	15%
1992	24,000					
1993	30,400					
1994	48,800			22,261	28,227	21%
1995	34,800					
1996	30,300					
1997	29,218			27,975	28,334	1%
1998	28,126					
1999	19,797					
2000	22,957			8,893	9,359	5%
2001	25,347					
2002	21,450	27,589	49,205	9,448	9,891	4%
2003	23,685					
2004	20,910 (0.195)	38,055	58,965	8,100	11,334	29%

* the Aleutian Islands estimates prior to 1990 were derived from surveys that were conducted using different protocols and are not comparable to more recent estimates.
The 1988 and 1991 slope estimates are from 200-800 m whereas earlier (and 2000) slope estimates are from 200-1,000m.

Table 5.4. Data sets used in the stock synthesis model for Greenland Turbot in the EBS. All size and age data are specified by sex.

Data Component	**Years of data**
Survey size at age data	1975, 1979-82
Shelf survey: size composition and biomass estimates	1979-2004
Slope survey: size composition and biomass estimates	1979, 81, 82, 85, 88, 91, 2002, 2004
Longline survey: size composition and abundance index	1996-2004
Total fishery catch data	1960-2004
Trawl fishery size composition	1977-87, 1989-91, 1993-2004
Longline fishery size composition	1977, 1979-85, 1992-2004

Table 5.5. Total fishing mortality rate, spawning and total biomass (compared with the past assessment) for BSAI Greenland turbot, 1960-2004.

			Female Spawning Biomass		Total Age 1+ Biomass	
Year	F	Catch / Mid-yr Biom.	2003 Assessment	Current Assessment	2003 Assessment	Current Assessment
1960	0.067	0.062	294,504	279,657	493,624	465,702
1961	0.111	0.104	277,664	262,002	467,843	439,870
1962	0.124	0.117	251,076	234,364	428,358	400,281
1963	0.075	0.068	224,565	207,175	390,631	362,348
1964	0.085	0.077	211,671	194,437	375,342	346,700
1965	0.026	0.023	199,061	181,863	364,865	334,917
1966	0.034	0.028	199,388	182,484	378,470	346,371
1967	0.061	0.049	199,976	182,938	406,943	369,853
1968	0.084	0.065	196,826	179,185	447,537	402,066
1969	0.078	0.060	191,725	172,650	499,012	442,091
1970	0.050	0.039	195,839	173,976	560,917	491,579
1971	0.091	0.076	222,379	195,437	635,826	553,316
1972	0.152	0.136	257,741	222,090	679,975	587,296
1973	0.125	0.116	284,360	237,421	669,661	570,848
1974	0.157	0.151	313,967	256,966	653,149	551,883
1975	0.148	0.143	324,025	259,766	606,854	505,846
1976	0.151	0.144	319,129	252,042	563,380	464,594
1977	0.084	0.073	298,155	231,333	521,549	425,082
1978	0.134	0.104	287,472	222,827	515,321	421,322
1979	0.140	0.106	267,019	205,528	496,681	404,184
1980	0.184	0.142	249,755	191,483	482,272	389,936
1981	0.215	0.169	230,017	174,164	455,790	362,919
1982	0.181	0.171	211,278	156,389	420,415	327,346
1983	0.183	0.177	198,441	142,817	383,374	291,297
1984	0.101	0.095	188,365	131,186	343,549	254,403
1985	0.069	0.064	189,119	130,876	322,224	237,843
1986	0.048	0.045	189,515	131,533	305,247	227,334
1987	0.049	0.045	187,061	131,060	291,055	221,103
1988	0.040	0.034	179,074	126,867	277,864	215,547
1989	0.063	0.043	168,763	121,987	268,055	212,348
1990	0.094	0.064	155,663	115,568	257,098	206,863
1991	0.072	0.041	142,476	109,099	242,783	196,966
1992	0.056	0.020	137,271	108,619	233,389	191,170
1993	0.133	0.046	136,751	110,758	228,686	189,379
1994	0.116	0.059	131,344	106,993	219,096	182,327
1995	0.110	0.050	123,712	100,616	206,690	172,145
1996	0.108	0.042	117,808	95,898	195,313	162,903
1997	0.129	0.049	114,000	93,184	184,488	154,169
1998	0.167	0.067	109,027	89,296	172,635	144,346
1999	0.107	0.046	100,848	82,280	158,975	132,526
2000	0.135	0.059	94,035	76,712	148,814	123,752
2001	0.102	0.049	85,771	69,719	138,098	114,082
2002	0.080	0.036	79,234	64,383	129,948	106,543
2003	0.080	0.035	74,461	60,589	124,558	101,465
2004	0.052	0.022		56,942		98,264

Table 5.6. Estimated beginning of year numbers of Greenland turbot by age and sex (millions).

Females

Yr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1974	24.95	17.36	11.20	7.56	13.07	19.12	14.45	11.01	8.47	6.55	1.48	1.14	0.89	0.71	0.58	0.42	0.32	0.25	0.20	0.16	0.78
1975	23.62	20.79	14.36	9.05	5.84	9.68	13.78	10.26	7.78	5.97	4.61	1.04	0.80	0.63	0.50	0.41	0.30	0.23	0.17	0.14	0.66
1976	31.75	19.69	17.21	11.63	7.03	4.36	7.03	9.88	7.32	5.54	4.25	3.28	0.74	0.57	0.45	0.36	0.29	0.21	0.16	0.12	0.57
1977	16.48	26.46	16.30	13.93	9.02	5.23	3.16	5.03	7.03	5.20	3.93	3.01	2.33	0.53	0.41	0.32	0.25	0.21	0.15	0.11	0.49
1978	34.00	13.75	22.00	13.39	11.19	7.10	4.06	2.44	3.87	5.40	3.99	3.02	2.31	1.79	0.40	0.31	0.24	0.19	0.16	0.12	0.46
1979	15.84	28.35	11.41	17.96	10.61	8.61	5.36	3.04	1.81	2.87	4.00	2.95	2.22	1.70	1.31	0.30	0.23	0.18	0.14	0.11	0.42
1980	12.92	13.21	23.53	9.31	14.22	8.15	6.50	4.01	2.26	1.34	2.12	2.94	2.16	1.62	1.24	0.95	0.21	0.16	0.13	0.10	0.39
1981	8.90	10.77	10.94	19.06	7.24	10.63	5.94	4.67	2.86	1.60	0.95	1.49	2.06	1.51	1.13	0.86	0.66	0.15	0.11	0.09	0.33
1982	5.34	7.41	8.91	8.82	14.64	5.31	7.56	4.16	3.24	1.97	1.10	0.65	1.01	1.39	1.01	0.75	0.57	0.44	0.10	0.08	0.28
1983	4.11	4.45	6.13	7.16	6.73	10.63	3.73	5.22	2.85	2.22	1.35	0.75	0.44	0.69	0.95	0.69	0.52	0.39	0.30	0.07	0.24
1984	7.87	3.42	3.68	4.92	5.46	4.88	7.45	2.57	3.58	1.95	1.52	0.92	0.51	0.30	0.47	0.65	0.47	0.35	0.27	0.20	0.21
1985	11.81	6.57	2.84	3.01	3.91	4.23	3.71	5.63	1.94	2.69	1.46	1.14	0.69	0.39	0.23	0.35	0.49	0.35	0.26	0.20	0.31
1986	11.95	9.86	5.46	2.34	2.43	3.11	3.32	2.90	4.38	1.51	2.09	1.14	0.89	0.54	0.30	0.18	0.28	0.38	0.28	0.21	0.40
1987	7.42	9.98	8.21	4.52	1.91	1.96	2.49	2.65	2.31	3.49	1.20	1.66	0.91	0.70	0.43	0.24	0.14	0.22	0.30	0.22	0.48
1988	4.75	6.19	8.31	6.79	3.69	1.54	1.57	1.98	2.10	1.83	2.77	0.95	1.32	0.72	0.56	0.34	0.19	0.11	0.17	0.24	0.56
1989	4.40	3.97	5.16	6.89	5.57	3.00	1.24	1.26	1.59	1.69	1.47	2.23	0.76	1.06	0.58	0.45	0.27	0.15	0.09	0.14	0.64
1990	6.52	3.68	3.31	4.31	5.75	4.65	2.48	1.01	1.01	1.26	1.33	1.16	1.75	0.60	0.83	0.45	0.35	0.21	0.12	0.07	0.61
1991	9.09	5.45	3.07	2.77	3.60	4.79	3.82	1.98	0.78	0.77	0.96	1.02	0.88	1.33	0.46	0.63	0.34	0.27	0.16	0.09	0.51
1992	3.68	7.59	4.55	2.57	2.31	3.00	3.97	3.11	1.59	0.62	0.61	0.76	0.80	0.69	1.04	0.36	0.49	0.27	0.21	0.13	0.47
1993	2.80	3.08	6.34	3.80	2.14	1.93	2.50	3.30	2.58	1.31	0.51	0.50	0.62	0.65	0.56	0.84	0.29	0.39	0.21	0.17	0.47
1994	2.53	2.33	2.57	5.30	3.17	1.79	1.61	2.08	2.71	2.10	1.05	0.41	0.39	0.48	0.50	0.42	0.63	0.21	0.29	0.16	0.47
1995	2.47	2.11	1.95	2.15	4.42	2.65	1.48	1.31	1.66	2.14	1.64	0.82	0.31	0.30	0.36	0.38	0.32	0.47	0.16	0.22	0.47
1996	3.74	2.06	1.77	1.63	1.79	3.69	2.20	1.21	1.06	1.33	1.70	1.29	0.64	0.24	0.23	0.28	0.29	0.24	0.36	0.12	0.52
1997	2.87	3.12	1.72	1.47	1.36	1.50	3.07	1.82	1.00	0.86	1.07	1.36	1.02	0.50	0.19	0.18	0.21	0.22	0.19	0.27	0.48
1998	2.52	2.40	2.61	1.44	1.23	1.14	1.25	2.54	1.49	0.81	0.69	0.85	1.06	0.79	0.38	0.14	0.13	0.16	0.16	0.14	0.56
1999	2.24	2.10	2.00	2.18	1.20	1.03	0.94	1.03	2.07	1.20	0.64	0.54	0.65	0.80	0.59	0.28	0.11	0.10	0.12	0.12	0.50
2000	2.89	1.87	1.76	1.67	1.82	1.00	0.86	0.78	0.84	1.68	0.97	0.51	0.43	0.51	0.62	0.46	0.22	0.08	0.07	0.09	0.46
2001	4.00	2.41	1.56	1.47	1.40	1.52	0.83	0.70	0.64	0.68	1.34	0.76	0.40	0.33	0.39	0.47	0.34	0.16	0.06	0.06	0.41
2002	5.71	3.34	2.01	1.31	1.23	1.16	1.26	0.69	0.57	0.51	0.54	1.06	0.60	0.31	0.25	0.30	0.36	0.26	0.12	0.05	0.35
2003	4.77	4.77	2.79	1.68	1.09	1.02	0.97	1.05	0.56	0.47	0.42	0.44	0.85	0.48	0.25	0.20	0.24	0.28	0.20	0.10	0.31
2004	7.35	3.98	3.99	2.33	1.41	0.91	0.85	0.80	0.86	0.46	0.38	0.34	0.35	0.68	0.38	0.19	0.16	0.18	0.22	0.16	0.31

Males

Yr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1974	24.95	17.36	11.20	7.56	13.14	19.43	14.82	11.35	8.74	6.76	1.53	1.18	0.93	0.75	0.62	0.47	0.36	0.29	0.23	0.19	1.03
1975	23.62	20.79	14.36	9.06	5.88	9.85	14.18	10.64	8.08	6.20	4.79	1.09	0.85	0.67	0.55	0.45	0.34	0.27	0.21	0.17	0.91
1976	31.75	19.69	17.21	11.64	7.08	4.44	7.24	10.28	7.65	5.79	4.44	3.44	0.79	0.61	0.49	0.40	0.33	0.25	0.20	0.16	0.81
1977	16.48	26.46	16.29	13.93	9.08	5.32	3.25	5.23	7.37	5.46	4.13	3.18	2.48	0.57	0.45	0.36	0.29	0.25	0.19	0.15	0.72
1978	34.00	13.75	22.00	13.39	11.24	7.19	4.16	2.53	4.04	5.68	4.21	3.19	2.46	1.92	0.44	0.35	0.28	0.23	0.19	0.15	0.68
1979	15.84	28.35	11.41	17.97	10.66	8.72	5.48	3.14	1.89	3.02	4.24	3.15	2.39	1.85	1.45	0.34	0.26	0.21	0.18	0.15	0.63
1980	12.92	13.21	23.53	9.32	14.29	8.26	6.63	4.12	2.35	1.41	2.25	3.17	2.36	1.80	1.39	1.10	0.25	0.20	0.16	0.13	0.60
1981	8.90	10.77	10.94	19.08	7.29	10.80	6.09	4.82	2.97	1.69	1.01	1.62	2.28	1.71	1.31	1.02	0.80	0.19	0.15	0.12	0.54
1982	5.34	7.41	8.90	8.82	14.76	5.41	7.79	4.32	3.38	2.08	1.18	0.71	1.14	1.61	1.21	0.93	0.73	0.58	0.14	0.11	0.48
1983	4.11	4.45	6.12	7.17	6.79	10.86	3.86	5.46	2.99	2.33	1.43	0.81	0.49	0.80	1.14	0.86	0.67	0.52	0.42	0.10	0.43
1984	7.87	3.42	3.68	4.93	5.51	4.99	7.73	2.70	3.77	2.06	1.61	0.99	0.57	0.35	0.56	0.81	0.62	0.48	0.38	0.30	0.38
1985	11.81	6.57	2.84	3.01	3.93	4.30	3.83	5.88	2.04	2.85	1.55	1.21	0.75	0.43	0.26	0.43	0.62	0.47	0.37	0.29	0.53
1986	11.95	9.86	5.46	2.34	2.44	3.14	3.39	3.00	4.60	1.59	2.22	1.21	0.95	0.59	0.34	0.21	0.34	0.49	0.38	0.29	0.65
1987	7.42	9.98	8.21	4.52	1.91	1.97	2.52	2.71	2.39	3.66	1.27	1.77	0.97	0.76	0.47	0.27	0.17	0.27	0.40	0.30	0.76
1988	4.75	6.19	8.31	6.79	3.69	1.55	1.58	2.01	2.16	1.91	2.91	1.01	1.41	0.77	0.61	0.38	0.22	0.13	0.22	0.32	0.86
1989	4.40	3.97	5.16	6.89	5.58	3.01	1.25	1.28	1.62	1.74	1.54	2.35	0.82	1.14	0.63	0.49	0.31	0.18	0.11	0.18	0.96
1990	6.52	3.68	3.31	4.31	5.75	4.66	2.51	1.04	1.04	1.31	1.39	1.23	1.87	0.65	0.91	0.50	0.39	0.25	0.14	0.09	0.91
1991	9.09	5.45	3.07	2.77	3.60	4.80	3.87	2.05	0.83	0.83	1.02	1.08	0.95	1.45	0.50	0.71	0.39	0.31	0.19	0.11	0.78
1992	3.68	7.59	4.55	2.57	2.31	3.01	4.00	3.20	1.68	0.68	0.67	0.82	0.87	0.76	1.16	0.40	0.57	0.31	0.25	0.15	0.72
1993	2.80	3.08	6.34	3.80	2.14	1.93	2.51	3.33	2.66	1.40	0.56	0.55	0.68	0.72	0.63	0.96	0.33	0.47	0.26	0.20	0.71
1994	2.53	2.33	2.57	5.30	3.17	1.79	1.61	2.09	2.77	2.20	1.15	0.46	0.45	0.56	0.58	0.51	0.78	0.27	0.38	0.21	0.74
1995	2.47	2.11	1.95	2.15	4.42	2.65	1.49	1.33	1.71	2.24	1.77	0.92	0.37	0.36	0.44	0.46	0.40	0.62	0.21	0.30	0.75
1996	3.74	2.06	1.77	1.63	1.79	3.69	2.21	1.23	1.10	1.39	1.82	1.43	0.74	0.30	0.29	0.35	0.37	0.32	0.49	0.17	0.84
1997	2.87	3.12	1.72	1.47	1.36	1.50	3.08	1.84	1.02	0.90	1.15	1.49	1.17	0.61	0.24	0.23	0.29	0.30	0.26	0.40	0.81
1998	2.52	2.40	2.61	1.44	1.23	1.14	1.25	2.56	1.52	0.85	0.74	0.94	1.22	0.95	0.49	0.20	0.19	0.23	0.24	0.21	0.98
1999	2.24	2.10	2.00	2.18	1.20	1.03	0.95	1.04	2.12	1.25	0.69	0.61	0.76	0.98	0.77	0.40	0.16	0.15	0.19	0.19	0.94
2000	2.89	1.87	1.76	1.67	1.82	1.00	0.86	0.79	0.86	1.75	1.03	0.57	0.49	0.62	0.80	0.62	0.32	0.13	0.12	0.15	0.92
2001	4.00	2.41	1.56	1.47	1.40	1.52	0.84	0.71	0.65	0.71	1.43	0.84	0.46	0.40	0.50	0.64	0.50	0.26	0.10	0.10	0.85
2002	5.71	3.34	2.01	1.31	1.23	1.17	1.27	0.69	0.59	0.53	0.58	1.16	0.68	0.37	0.32	0.40	0.52	0.40	0.21	0.08	0.77
2003	4.77	4.77	2.79	1.68	1.09	1.02	0.97	1.05	0.58	0.49	0.44	0.47	0.95	0.56	0.30	0.26	0.33	0.42	0.33	0.17	0.69
2004	7.35	3.98	3.99	2.33	1.41	0.91	0.85	0.81	0.88	0.48	0.40	0.36	0.39	0.78	0.46	0.25	0.22	0.27	0.35	0.27	0.70

Table 5.7. Age-equivalent sex-specific selectivity estimates (for 2004) from each gear type for Greenland turbot in the BSAI. Note that selectivity processes are modeled as a function of size.

	Trawl Fishery		Longline fishery		Shelf Survey		Slope survey		Longline survey	
Age	F	M	F	M	F	M	F	M	F	M
1	0	0	0	0	0.05	0.05	0	0	0	0
2	0	0	0	0	0.77	0.6	0	0	0	0
3	0	0	0	0	0.54	0.35	0.01	0.01	0	0
4	0	0	0	0	0.43	0.27	0.03	0.02	0	0
5	0.03	0.01	0	0	0.38	0.23	0.05	0.04	0	0
6	0.18	0.06	0.01	0	0.35	0.21	0.09	0.07	0.02	0.01
7	0.52	0.2	0.03	0.01	0.34	0.2	0.14	0.09	0.06	0.02
8	0.81	0.41	0.07	0.02	0.33	0.19	0.19	0.12	0.14	0.05
9	0.94	0.61	0.15	0.03	0.33	0.18	0.25	0.15	0.24	0.08
10	0.98	0.75	0.24	0.05	0.33	0.18	0.32	0.18	0.36	0.11
11	0.99	0.83	0.35	0.08	0.33	0.18	0.38	0.2	0.47	0.15
12	0.99	0.87	0.45	0.1	0.33	0.18	0.44	0.22	0.57	0.19
13	0.99	0.89	0.55	0.13	0.33	0.18	0.5	0.24	0.65	0.22
14	0.99	0.89	0.63	0.15	0.33	0.17	0.55	0.26	0.72	0.25
15	0.99	0.88	0.69	0.17	0.33	0.17	0.59	0.27	0.77	0.28
16	0.99	0.86	0.74	0.19	0.33	0.17	0.63	0.29	0.81	0.3
17	0.99	0.85	0.78	0.21	0.32	0.17	0.67	0.3	0.84	0.32
18	0.99	0.84	0.82	0.22	0.32	0.17	0.7	0.31	0.86	0.34
19	0.99	0.83	0.84	0.23	0.32	0.17	0.72	0.31	0.88	0.35
20	0.99	0.82	0.86	0.24	0.32	0.17	0.74	0.32	0.9	0.36
21	0.99	0.79	0.9	0.27	0.32	0.17	0.8	0.34	0.93	0.39

Table 5.8. Age-equivalent sex-specific weights-at-age estimates by each fishery and proportion mature female weight-at-age at time of spawning for Greenland turbot in the BSAI. Units are kg.

	Trawl fishery		Longline fishery		
Age	Females	Males	Females	Males	Wt · Maturity
1	0.1	0	0.1	0	0.0
2	0.2	0.2	0.3	0.2	0.0
3	0.7	0.4	0.8	0.4	0.0
4	1.6	0.8	1.6	0.8	0.0
5	2.9	1.3	2.7	1.2	0.0
6	4.1	1.8	4.0	1.7	0.5
7	5.1	2.2	5.5	2.1	1.8
8	6.0	2.5	6.9	2.5	3.8
9	7.1	2.7	8.3	2.9	5.7
10	8.3	2.9	9.6	3.2	7.4
11	9.5	3.1	10.9	3.5	8.8
12	10.7	3.2	12.0	3.7	10.1
13	11.9	3.4	13.1	3.9	11.4
14	13.0	3.5	14.1	4.1	12.5
15	14.0	3.6	15.1	4.2	13.6
16	14.9	3.7	15.8	4.4	14.6
17	15.7	3.7	16.5	4.5	15.4
18	16.4	3.8	17.1	4.5	16.1
19	17.0	3.9	17.6	4.6	16.7
20	17.5	3.9	18.0	4.7	17.3
21	18.7	4.0	19.2	4.8	18.8

Table 5.9. Mean spawning biomass, F, and yield projections for Greenland turbot, 2004-2017. The full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed **equal**. The values for $B_{40\%}$ and $B_{35\%}$ are 51,600 and 45,100 tons, respectively.

Female sp. Biomass	***Max F_{ABC}***	***Author's F_{ABC}***	***Half max F_{ABC}***	***5-year avg.***	***No Fishing***	***Scenario 6***	***Scenario 7***
2004	58,133	58,133	58,133	58,133	58,133	58,133	58,133
2005	55,574	55,574	55,574	55,574	55,574	55,574	55,574
2006	43,121	51,981	48,630	51,981	55,029	40,393	43,121
2007	37,100	49,814	44,440	49,814	55,374	34,017	37,100
2008	35,193	49,301	42,948	49,301	56,904	32,247	33,884
2009	35,890	50,527	43,646	50,527	59,822	33,126	34,011
2010	38,204	53,276	45,943	53,276	64,039	35,546	35,999
2011	41,438	57,249	49,320	57,249	69,361	38,765	38,967
2012	44,560	61,593	52,853	61,593	74,952	41,741	41,805
2013	47,204	66,013	56,308	66,013	80,636	44,097	44,098
2014	49,240	70,213	59,454	70,213	86,159	45,749	45,729
2015	50,715	74,036	62,168	74,036	91,377	46,812	46,790
2016	51,699	77,416	64,404	77,416	96,239	47,422	47,405
2017	52,311	80,286	66,162	80,286	100,605	47,726	47,716
Fishing Mort	***Scenario 1***	***Scenario 2***	***Scenario 3***	***Scenario 4***	***Scenario 5***	***Scenario 6***	***Scenario 7***
2004	0.046	0.046	0.046	0.046	0.046	0.046	0.046
2005	0.391	0.090	0.196	0.090	0.000	0.500	0.391
2006	0.324	0.090	0.184	0.090	0.000	0.386	0.324
2007	0.276	0.090	0.167	0.090	0.000	0.321	0.352
2008	0.261	0.090	0.161	0.090	0.000	0.303	0.320
2009	0.266	0.090	0.164	0.090	0.000	0.312	0.321
2010	0.285	0.090	0.173	0.090	0.000	0.337	0.341
2011	0.310	0.090	0.184	0.090	0.000	0.369	0.371
2012	0.331	0.090	0.190	0.090	0.000	0.397	0.398
2013	0.344	0.090	0.191	0.090	0.000	0.415	0.415
2014	0.352	0.090	0.192	0.090	0.000	0.426	0.426
2015	0.356	0.090	0.193	0.090	0.000	0.431	0.431
2016	0.359	0.090	0.193	0.090	0.000	0.435	0.435
2017	0.361	0.090	0.194	0.090	0.000	0.436	0.436
Yield	***Scenario 1***	***Scenario 2***	***Scenario 3***	***Scenario 4***	***Scenario 5***	***Scenario 6***	***Scenario 7***
2004	2,156	2,156	2,156	2,156	2,156	2,156	2,156
2005	15,547	3,928	8,283	3,928	0	19,198	15,547
2006	10,124	3,662	6,803	3,662	0	11,073	10,124
2007	7,315	3,449	5,560	3,449	0	7,657	9,139
2008	6,287	3,315	5,007	3,315	0	6,543	7,282
2009	6,176	3,265	4,933	3,265	0	6,498	6,910
2010	6,666	3,312	5,233	3,312	0	7,121	7,355
2011	7,572	3,442	5,758	3,442	0	8,193	8,317
2012	8,527	3,624	6,198	3,624	0	9,321	9,375
2013	9,345	3,847	6,607	3,847	0	10,270	10,287
2014	10,000	4,095	7,020	4,095	0	10,987	10,988
2015	10,509	4,346	7,415	4,346	0	11,478	11,473
2016	10,883	4,588	7,770	4,588	0	11,808	11,804
2017	11,139	4,806	8,073	4,806	0	12,000	11,997

Table 5.10. Estimated total Greenland turbot harvest by area, 1977-2004.

Year	EBS	Aleutians	Year	EBS	Aleutians
1977	27,708	2,453	1991	3,781	4,397
1978	37,423	4,766	1992	1,767	2,462
1979	34,998	6,411	1993	4,878	6,330
1980	48,856	3,697	1994	3,875	7,141
1981	52,921	4,400	1995	4,499	5,855
1982	45,805	6,317	1996	4,258	4,844
1983	43,443	4,115	1997	5,730	6,435
1984	21,317	1,803	1998	7,839	8,329
1985	14,698	33	1999	5,179	5,391
1986	7,710	2,154	2000	5,667	5,888
1987	6,519	3,066	2001	4,102	4,252
1988	6,064	1,044	2002	3,011	3,153
1989	4,061	4,761	2003	2,467	960
1990	7,702	2,494	2004	1,775	381

Table 5.11. Summary management values based on this assessment. Note that the fishing mortality rates assume 50% contribution from longline gear and 50% from trawl.

Management Parameter	Value
M	0.18 yr-1
Amendment 56 Tier (in 2002)	3a
Approximate age at full recruitment	10 years
$F_{35\%}$ (F_{OFL})	0.50
$F_{40\%}$	0.39
$B_{100\%}$	129,000 t
$B_{40\%}$	51,600 t
$B_{35\%}$	45,100 t
Year 2005 female spawning biomass	55,600 t
Year 2004 total (age 1+) biomass	98,300 t
$F_{ABC} = F_{40\%}$ (max permissible)	0.39
Maximum permissible ABC	15,500
F_{ABC} = 5-year average	0.07
Recommended ABC	**3,930**
$F_{overfishing} = F_{35\%}$	0.50
Overfishing level	**19,200 t**

Figures

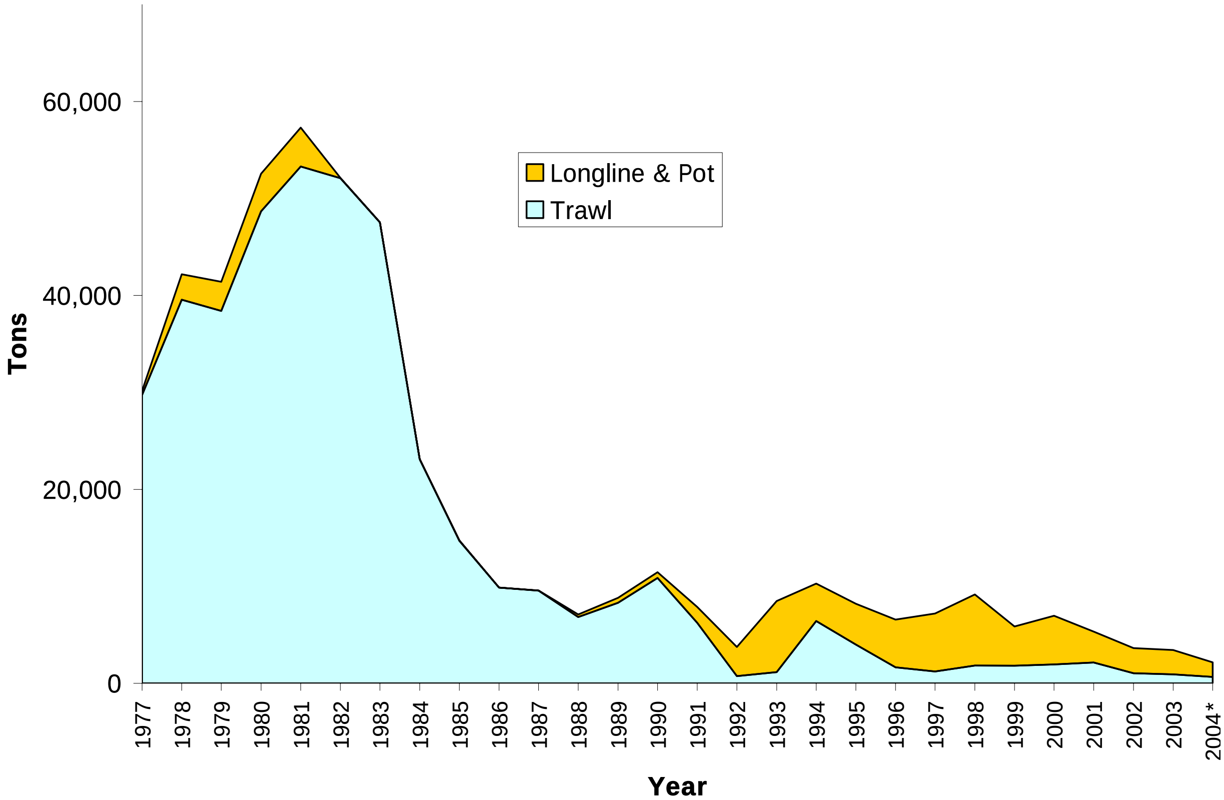


Figure 5.1. Comparison of trawl (1960-2004) and longline (1977-2004) catches of Greenland turbot in the combined EBS/AI area. Note: catches to October 30th, 2004.

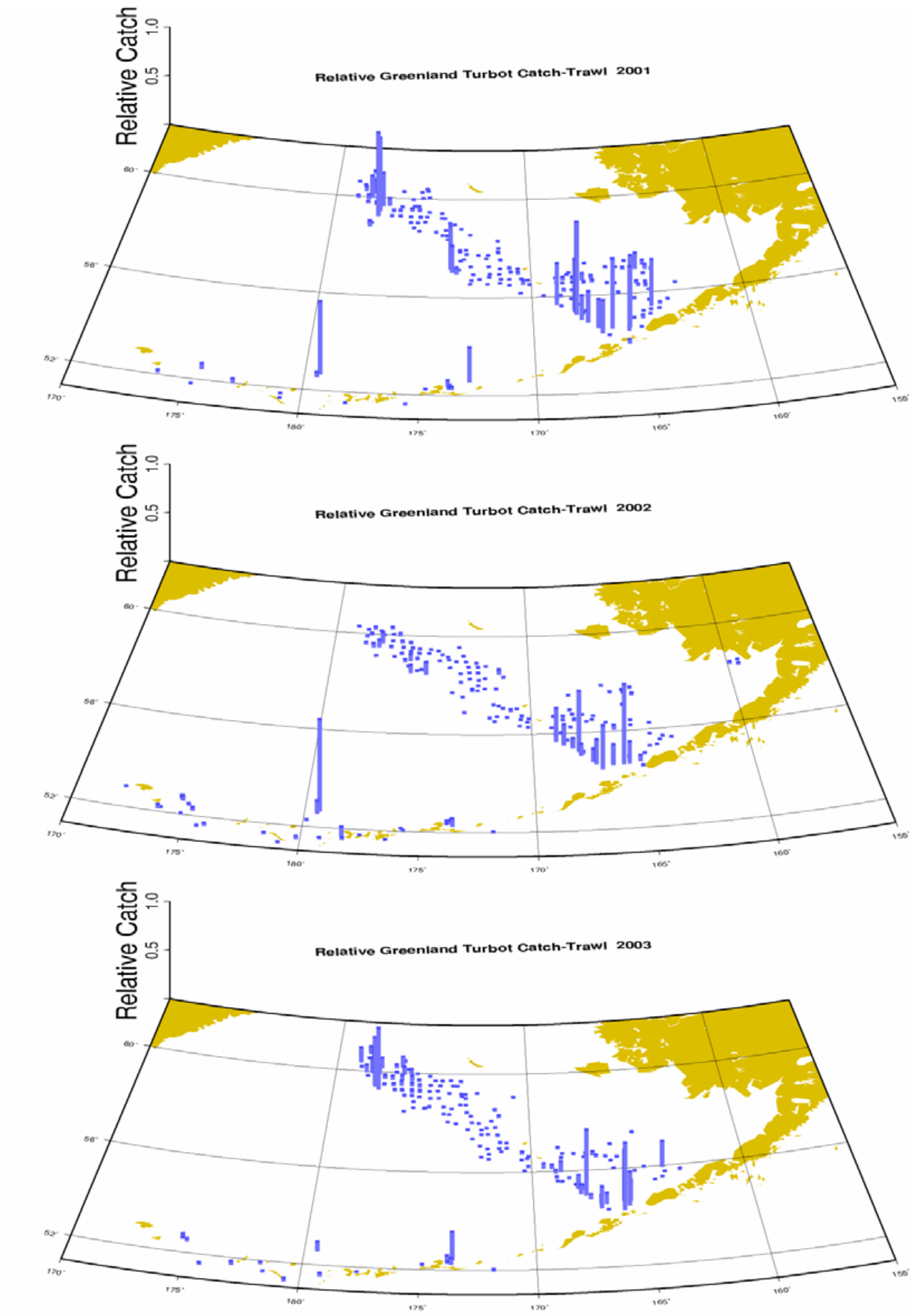


Figure 5.2. Distribution of Greenland turbot catch by trawl vessels based on aggregated NMFS observer data, 2001-2003. Vertical lines represent the relative magnitude of Greenland turbot catch for each 30' longitude by 15' latitude grids.

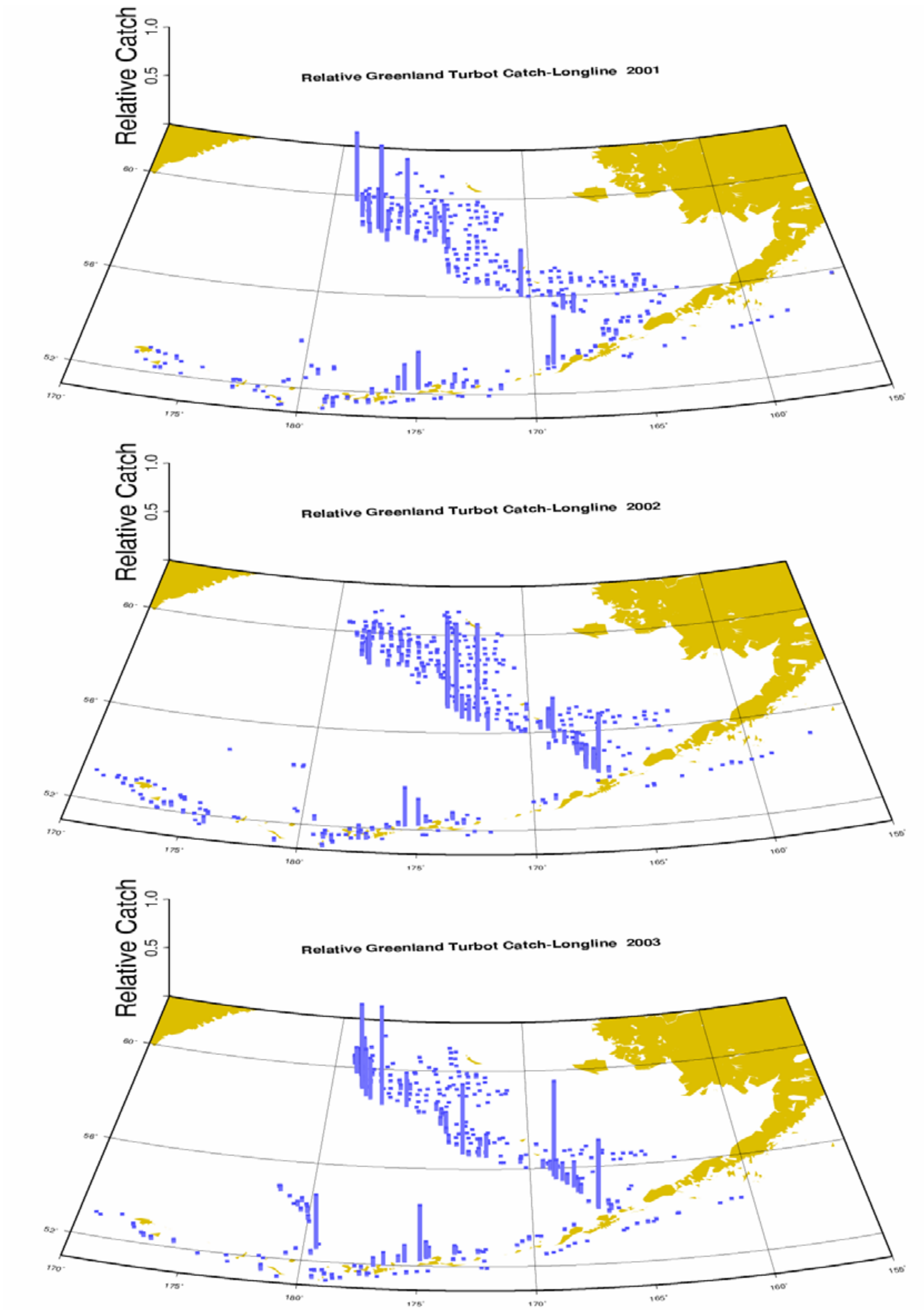


Figure 5.3. Distribution of Greenland turbot catch by longline vessels based on aggregated NMFS observer data, 2001-2003. Vertical lines represent the relative magnitude of Greenland turbot catch for each 30' longitude by 15' latitude grids.

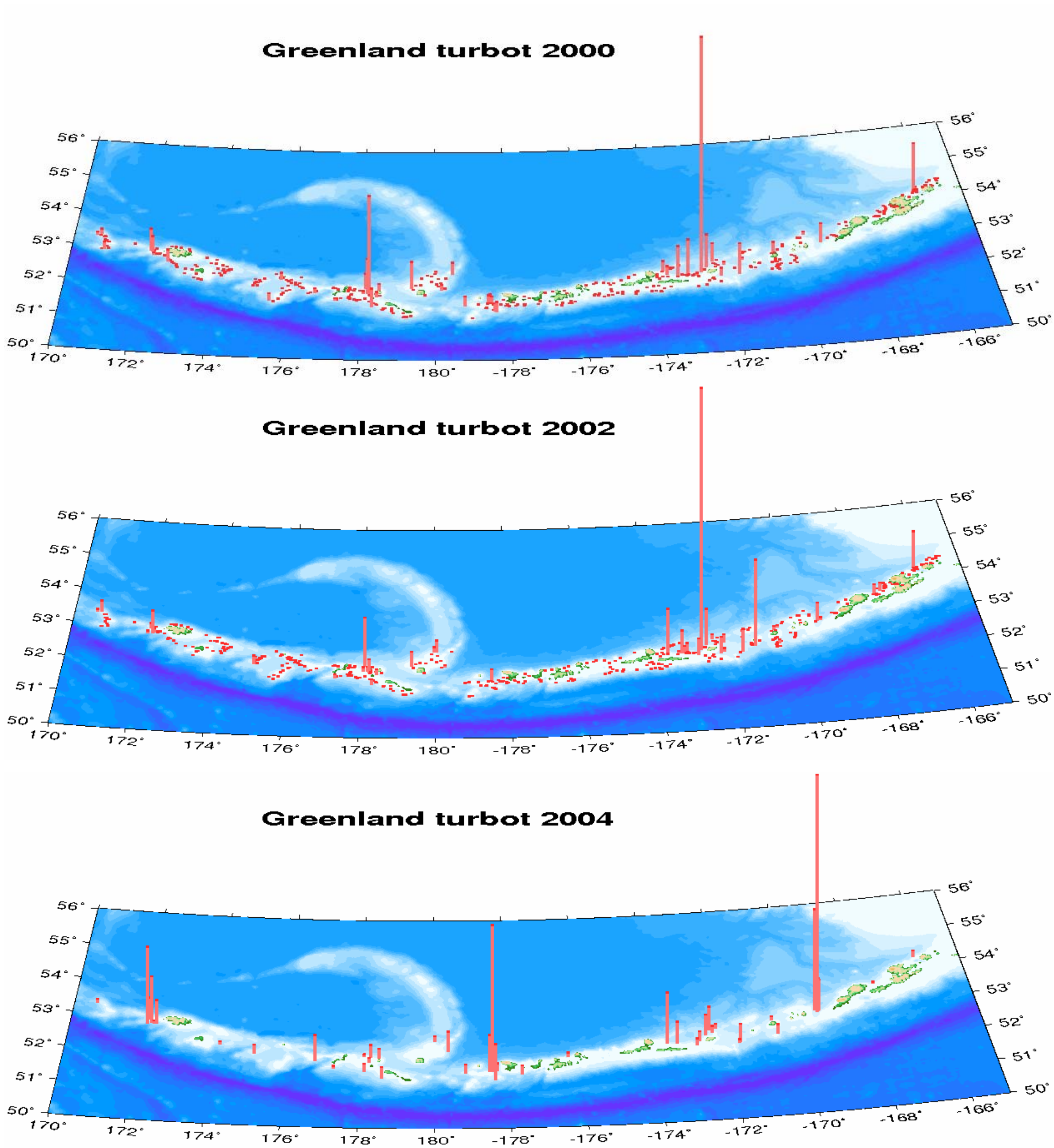


Figure 5.4. Greenland turbot catch per unit effort from the Aleutian Islands region bottom trawl survey, 2000-2004.

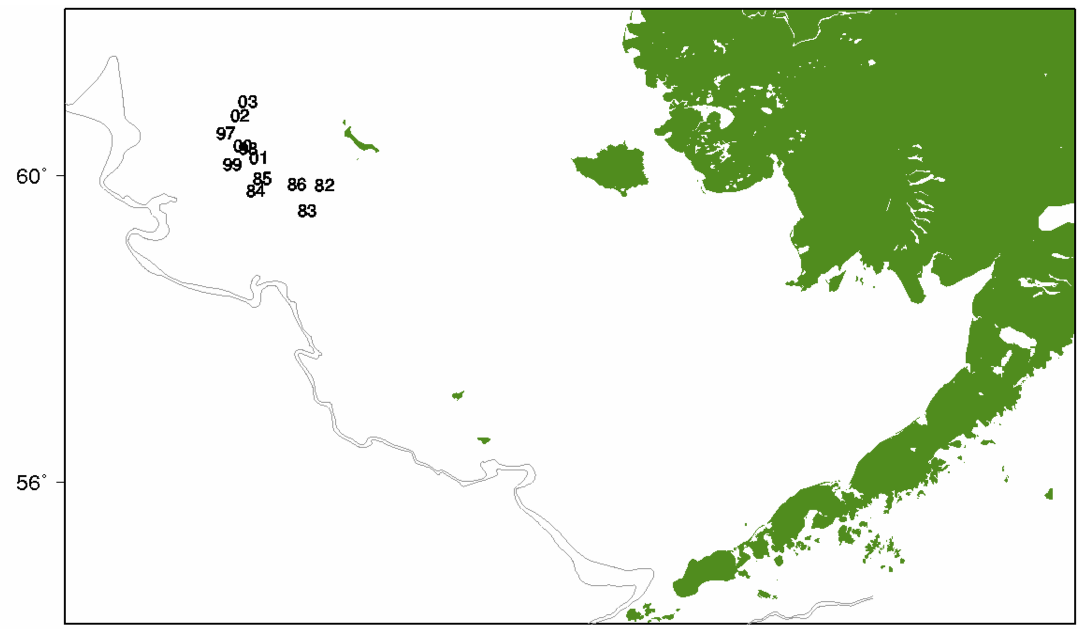


Figure 5.5. Centers of Greenland turbot summer-time EBS shelf distributions as estimated from NMFS bottom trawl survey data, 1982-1986 and 1997-2003 (other years omitted for presentation clarity). Figure courtesy P. Spencer, NMFS/AFSC.

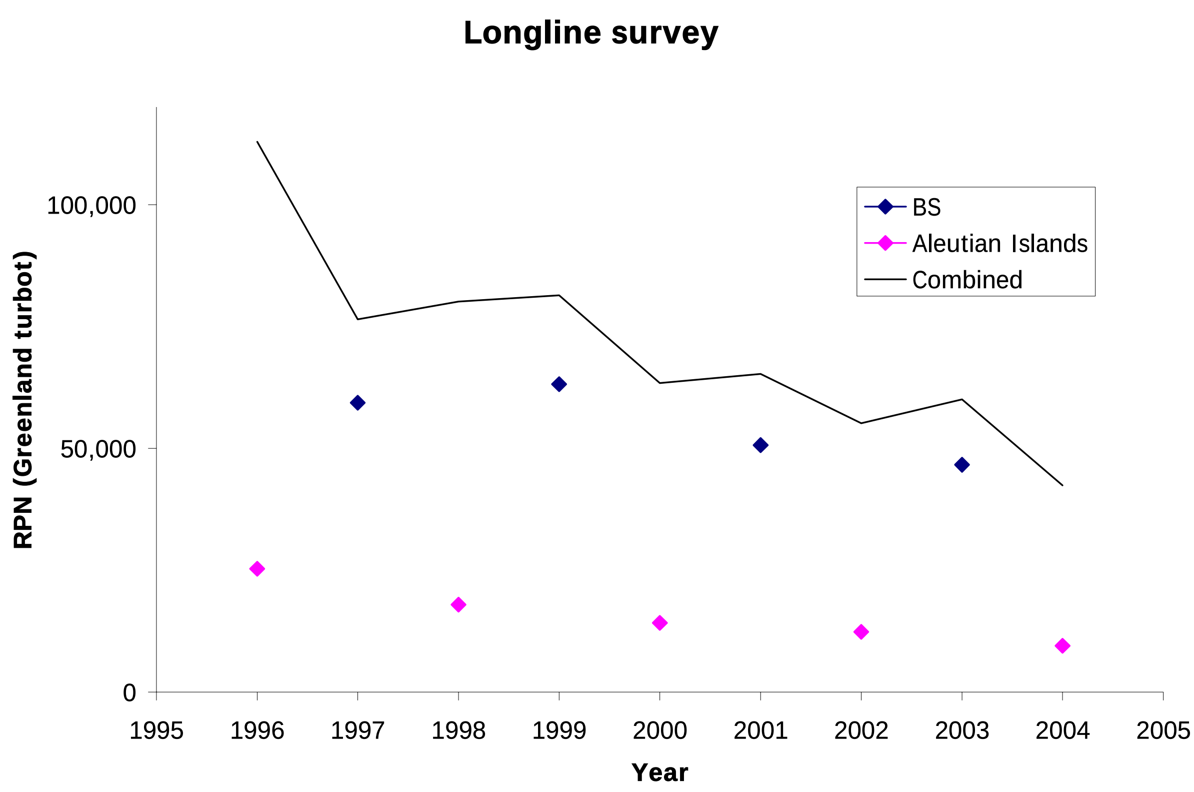
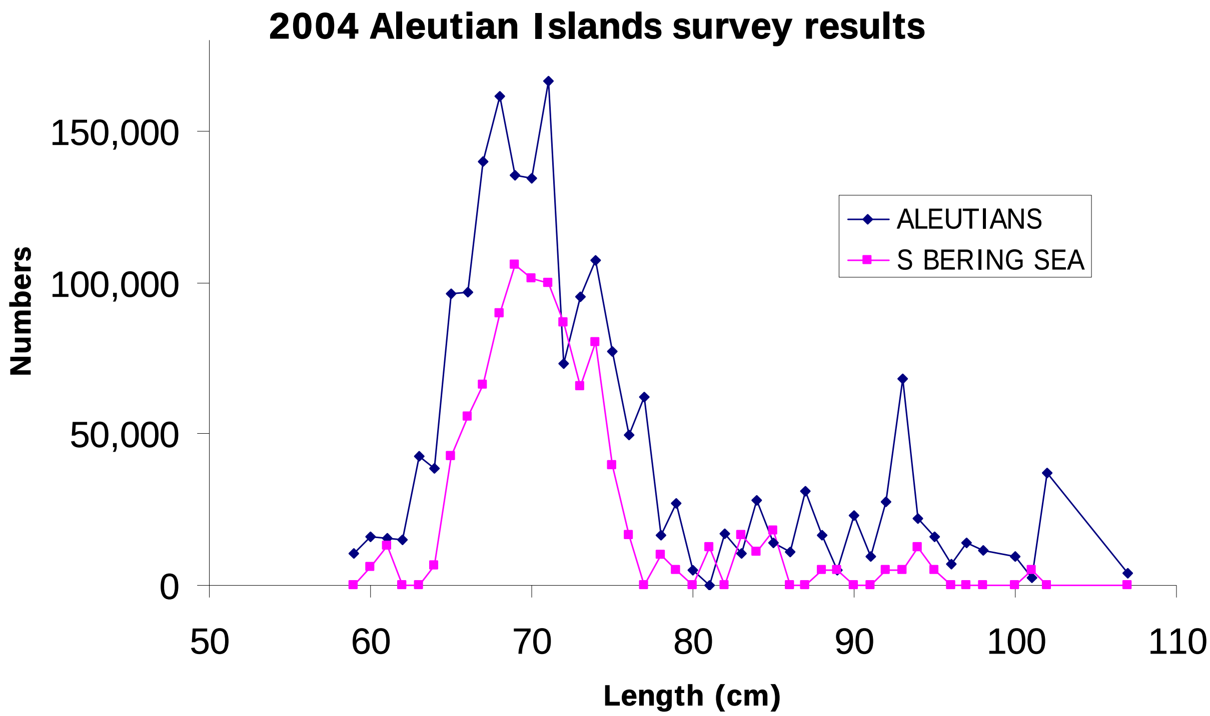


Figure 5.6. Greenland turbot longline survey abundance trends (RPN=relative population number) for the two regions and the combined values used in the assessment model.



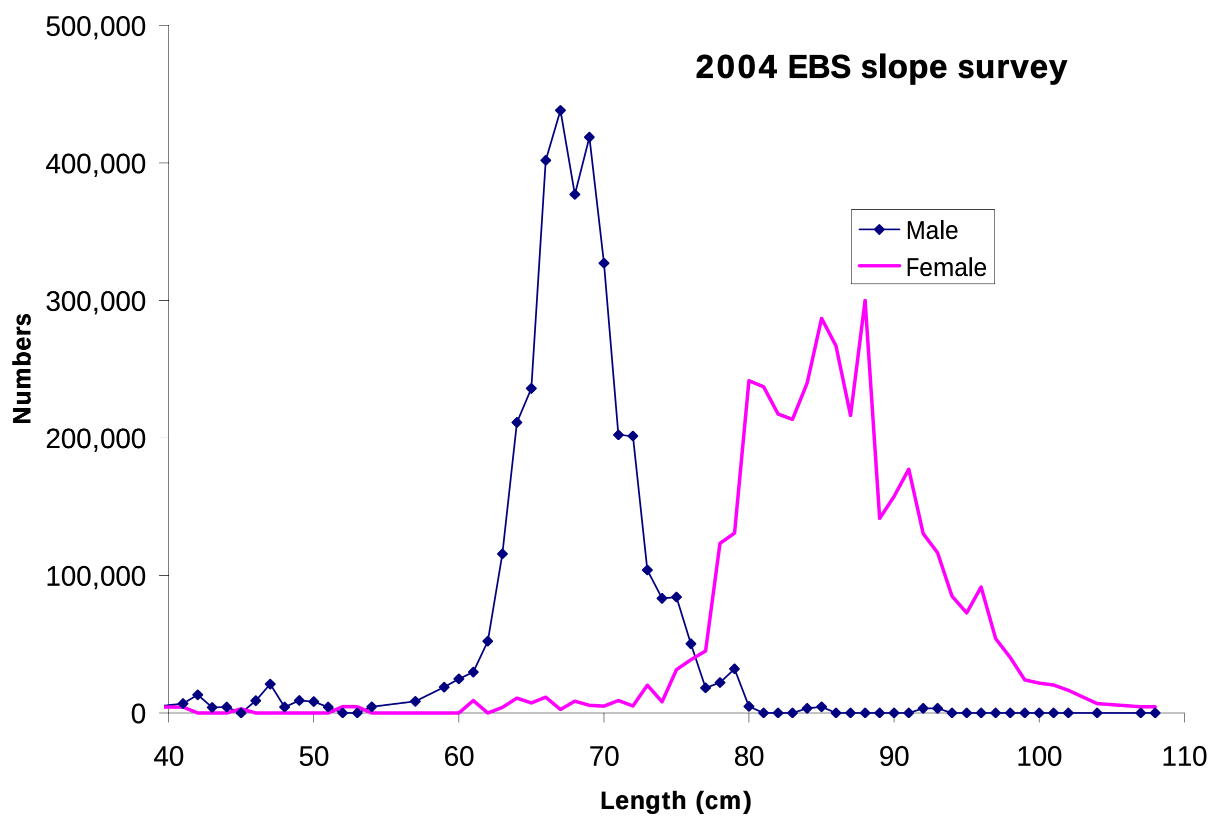


Figure 5.7. Relative length (cm) frequency of Greenland turbot observed from the summer 2004 NMFS bottom trawl Aleutian Islands (top) and EBS slope surveys (bottom).

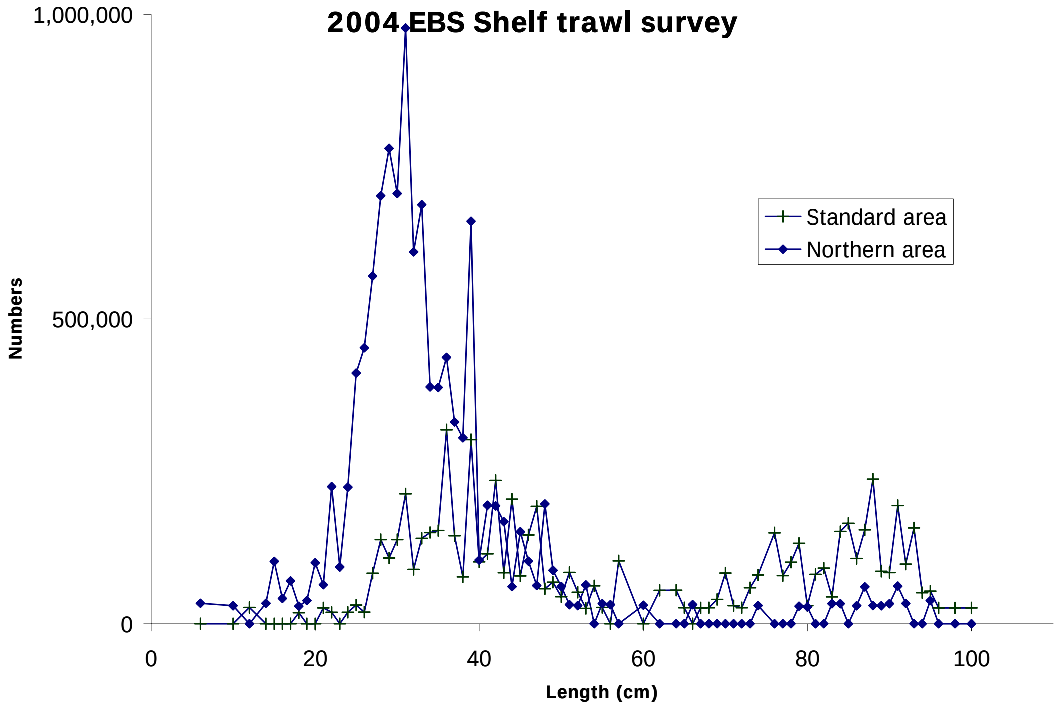


Figure 5.8. Length frequency of Greenland turbot observed from the summer 2004 NMFS EBS shelf bottom trawl survey for the standard area and the northern portion.

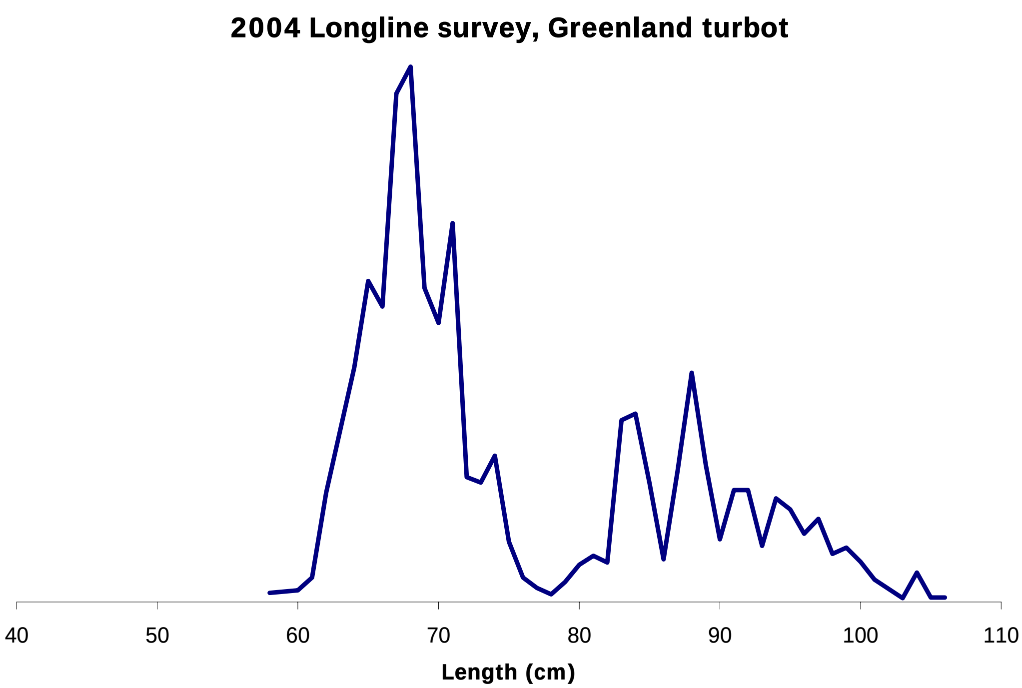


Figure 5.9. Length frequency of Greenland turbot observed from the summer 2004 NMFS longline survey (covering the eastern portion of the Aleutian Islands).

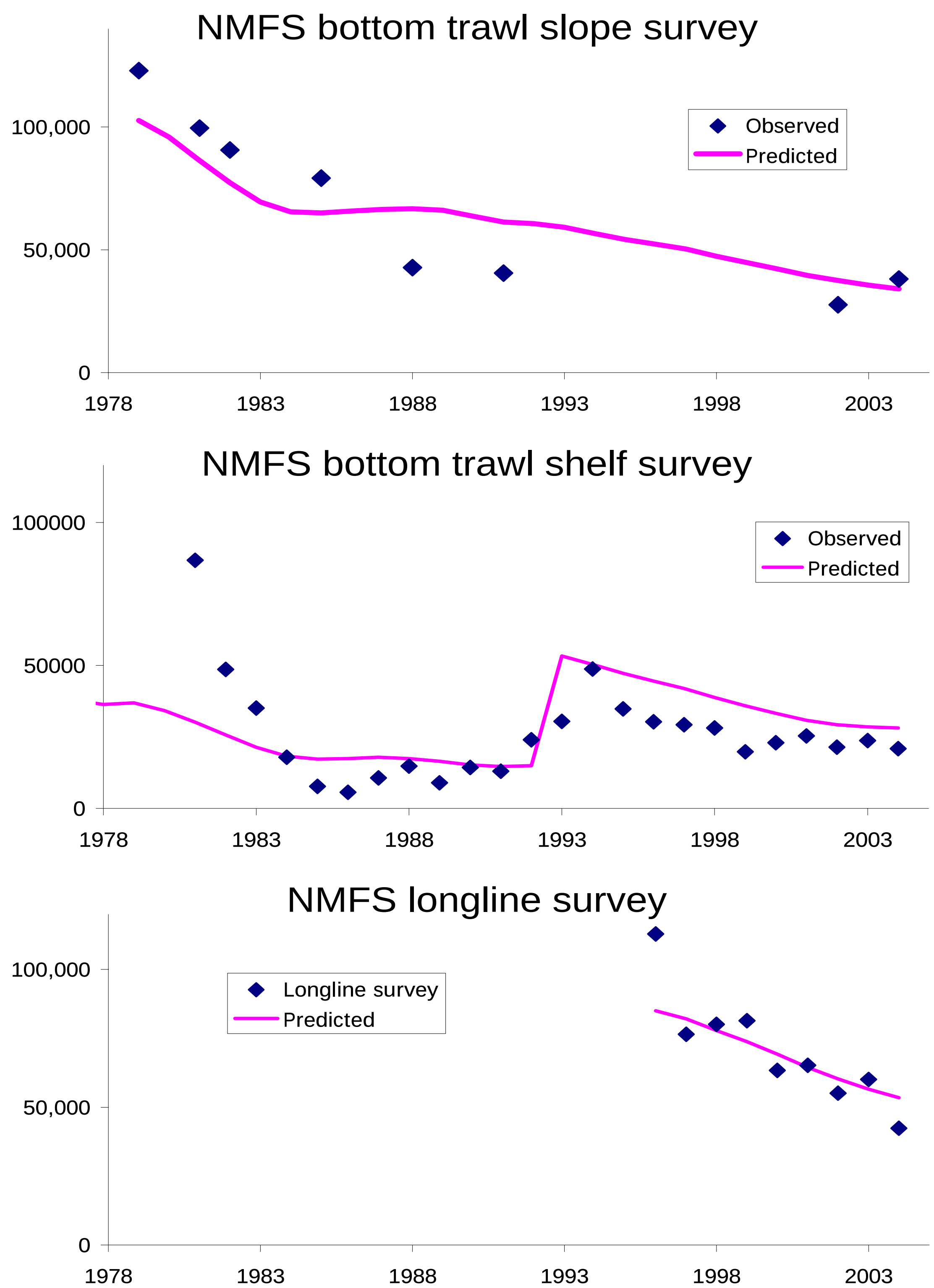


Figure 5.10. Fits to the different survey and fishery indices for Greenland turbot in the EBS/AI region.

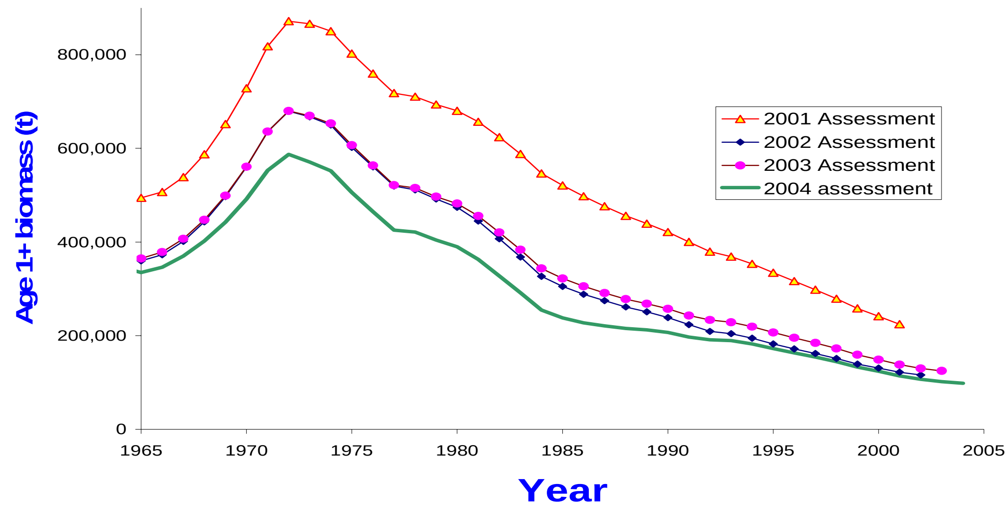


Figure 5.11 Total age 1+ biomass trend for Greenland turbot in the EBS/AI region, 1965-2004 compared to previous assessments.

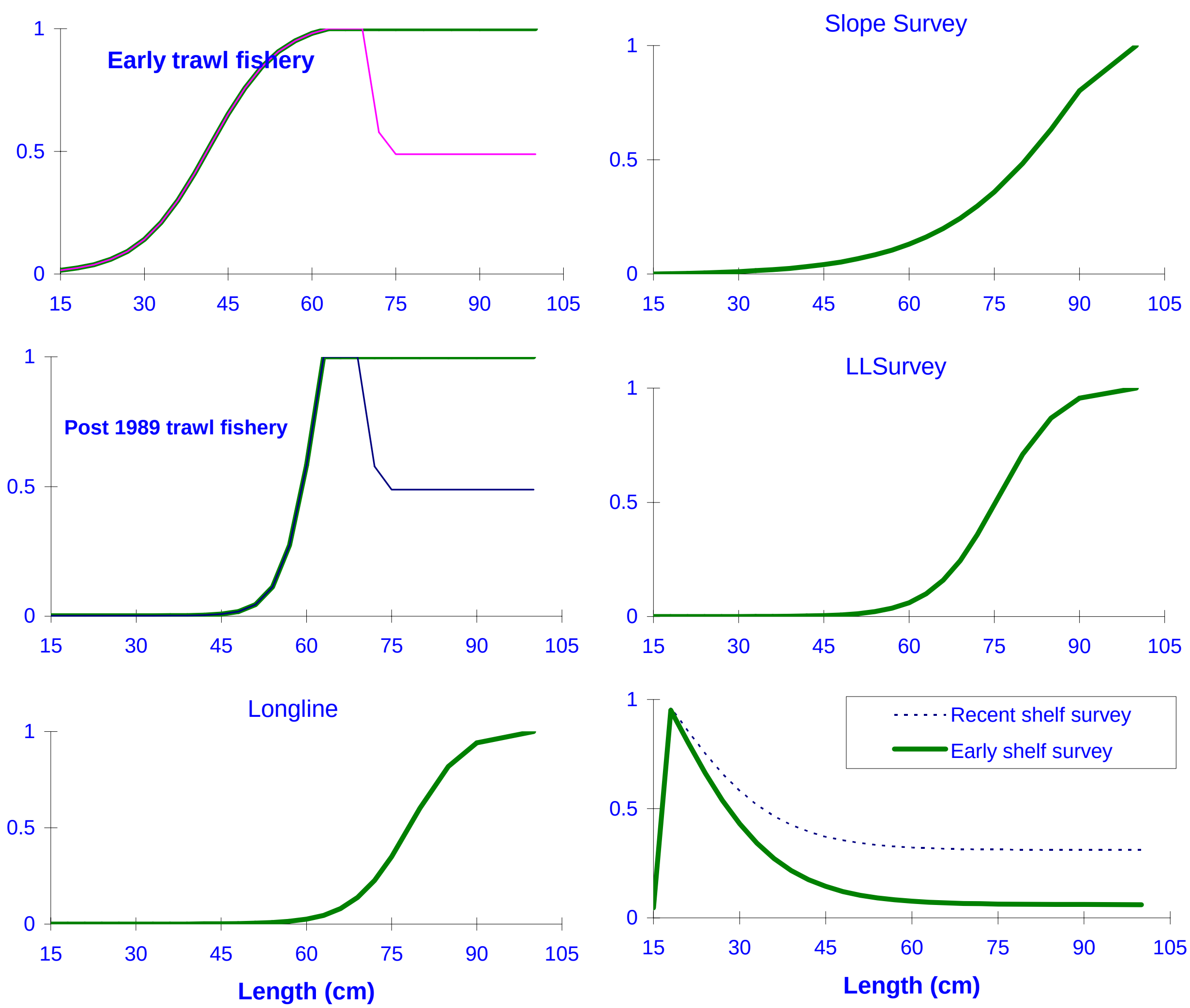


Figure 5.12. Size-specific selectivity patterns for surveys and fisheries of Greenland turbot in the EBS/AI region. Thin lines represent differential selectivity of males.

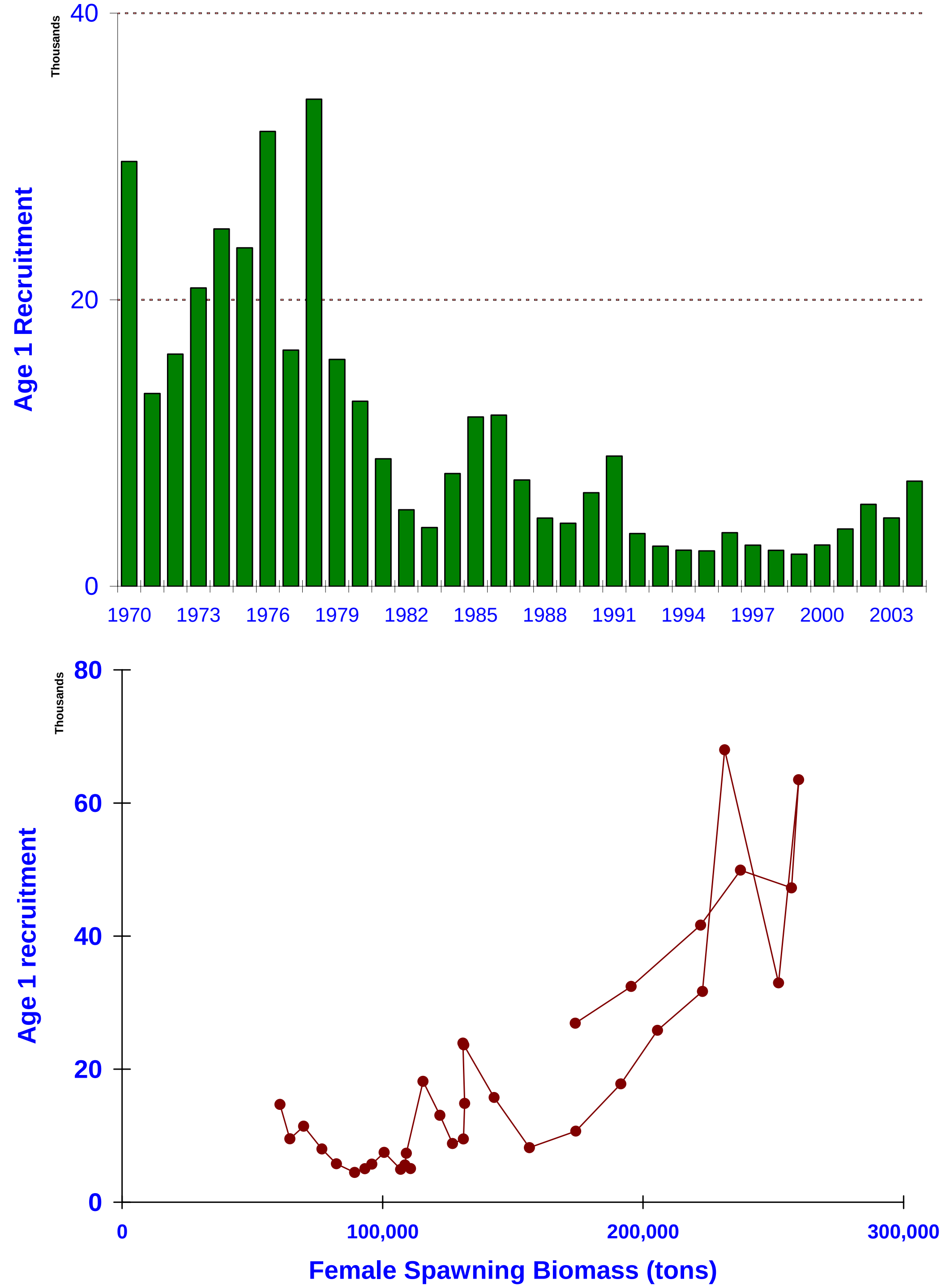


Figure 5.13. Estimated recruitment to age 1 (thousands; upper panel) and the observed stock-recruitment pattern (lower panel) of Greenland turbot in the EBS/AI region, 1970-2004.

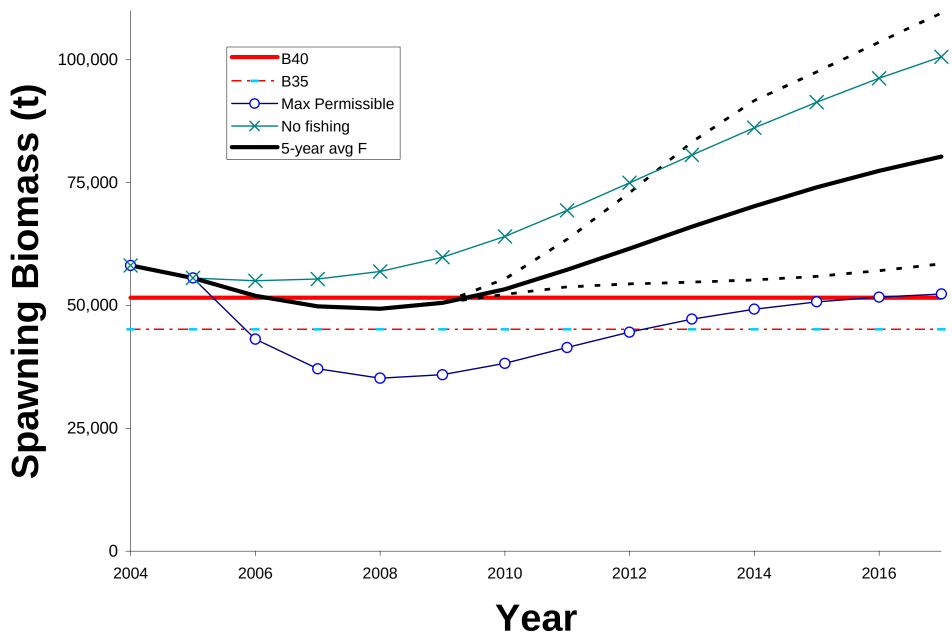


Figure 5.14. Stochastic trajectory of Greenland turbot female spawning biomass and projected levels for the maximum allowable fishing mortality rate under Amendment 56/56, Tier 3 and showing the mean expected value fishing under a constant *F* based on the recent 5-year average, the maximum permissible level, and under no fishing. These runs assume (conservatively) that the relative fishing mortality rates between longline and trawl fishing gear are equal. The dotted lines represent the upper and lower 90% confidence limits.

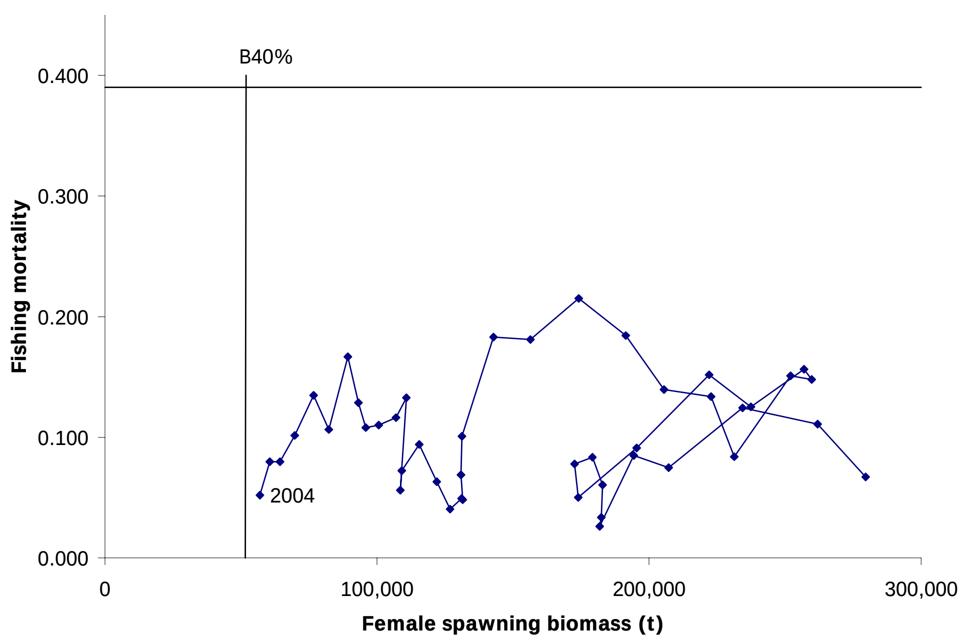
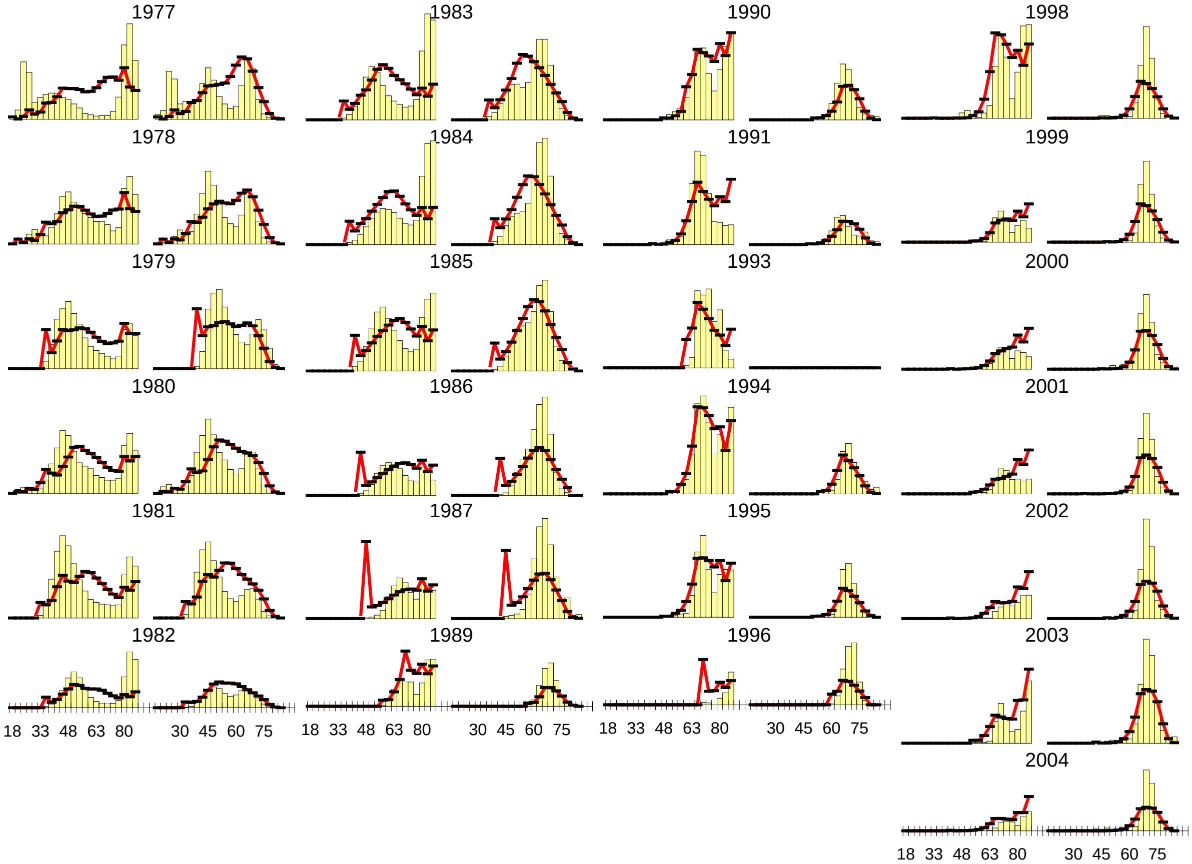


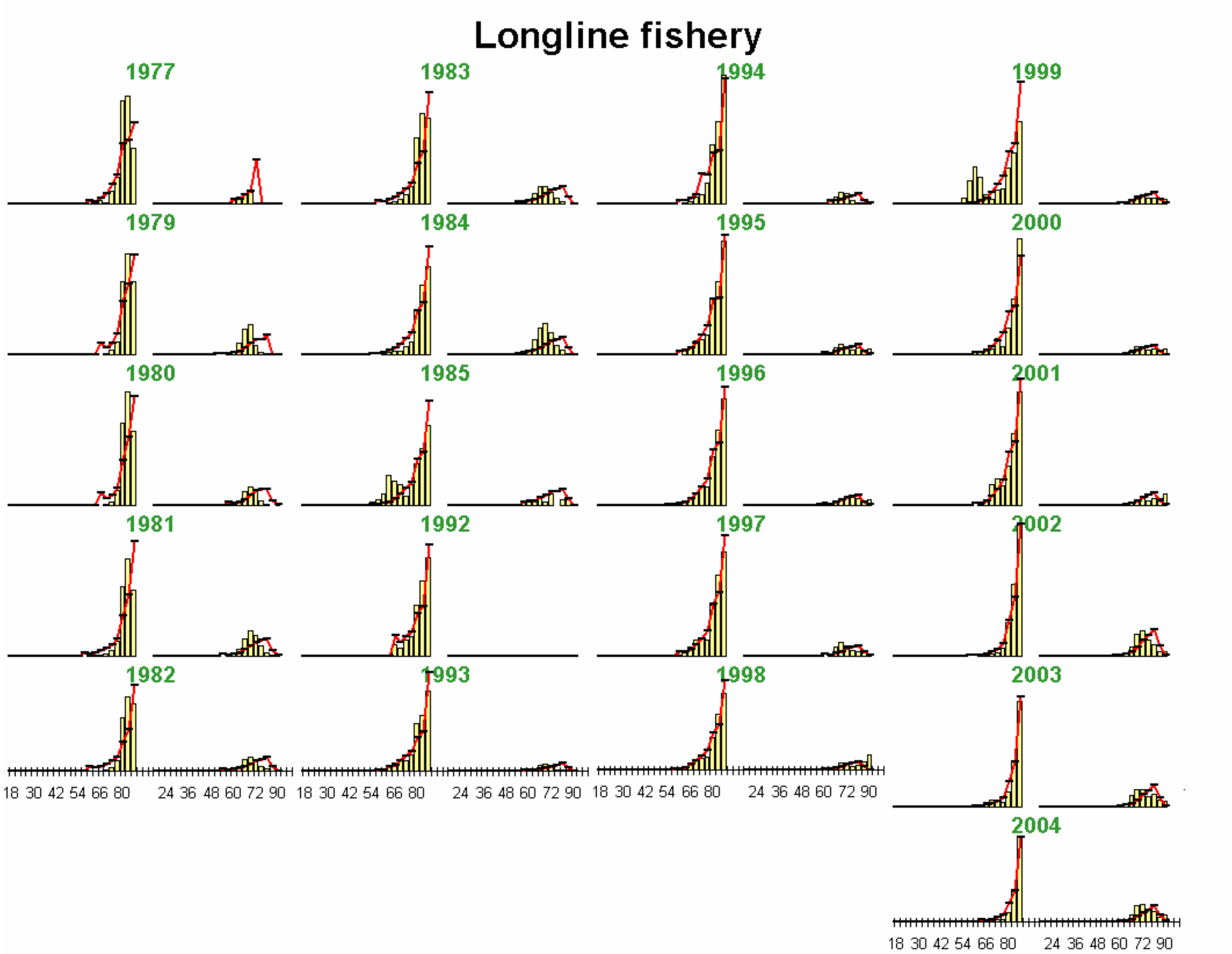
Figure 5.15. Historical estimates of total fishing mortality (vertical axis) and female spawning biomass relative to $B_{40\%}$ and $F_{40\%}$ levels for EBS Greenland turbot.

Appendix 5.1 Fits to the size composition data

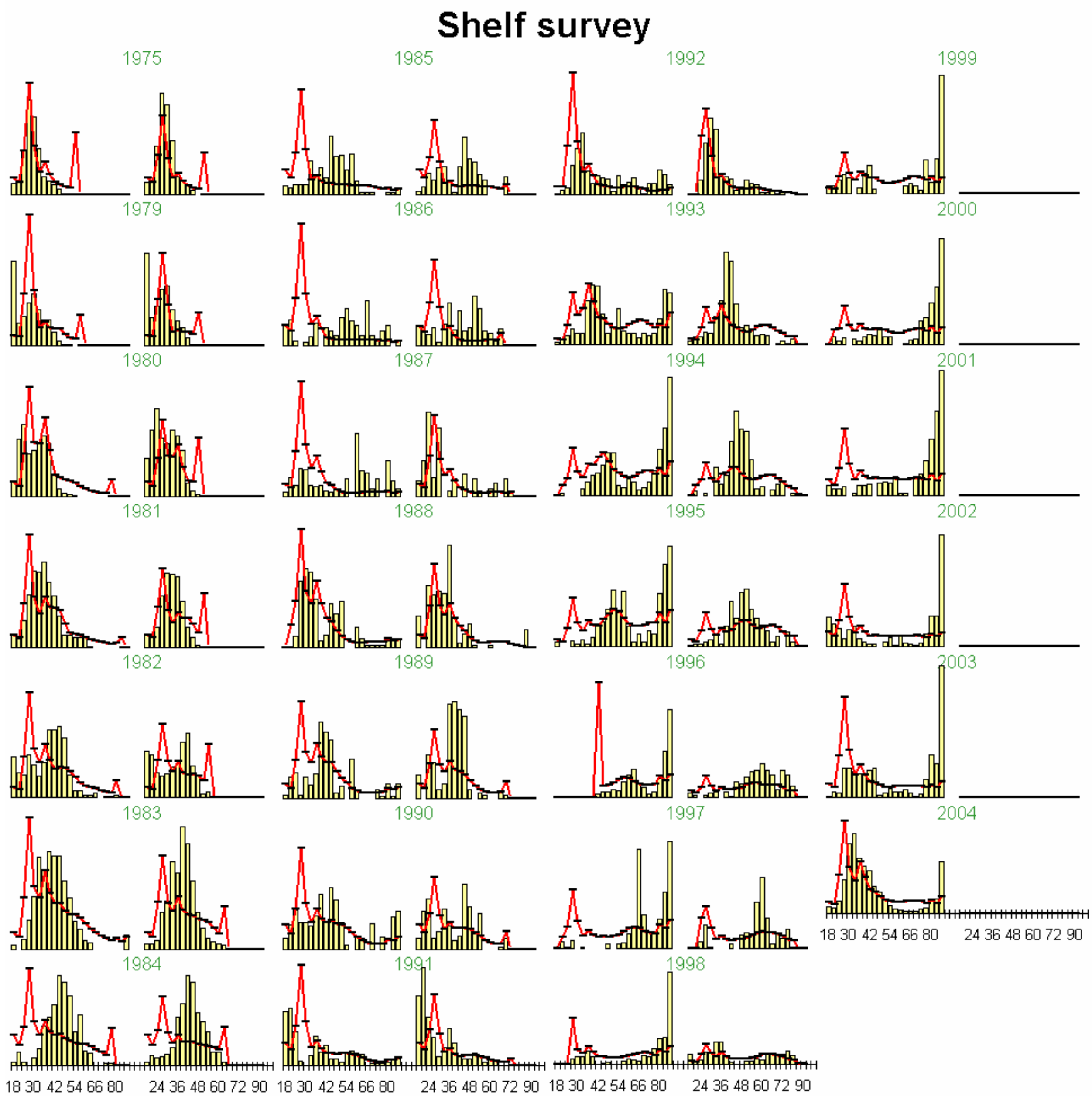
Trawl fishery



Legend: Greenland turbot relative length (cm) frequency data are presented by the bars and the model predictions are shown by the lines. For each panel, the left side represents the female component and the right side are for the males—if only one set is shown then the data are only available as both sexes combined.



Legend: Greenland turbot relative length (cm) frequency data are presented by the bars and the model predictions are shown by the lines. For each panel, the left side represents the female component and the right side are for the males—if only one set is shown then the data are only available as both sexes combined.



Legend: Greenland turbot relative length (cm) frequency data are presented by the bars and the model predictions are shown by the lines. For each panel, the left side represents the female component and the right side are for the males—if only one set is shown then the data are only available as both sexes combined.

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